THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE EIGHTY-FIFTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the Royal Society of Arts on Thursday evening, April 23rd, 1925, SIR FREDERICK W. BLACK, K.C.B., Past-President, occupying the Chair.

The Chairman, at the opening, said that as the meeting was an extra one there was no preliminary business for the Secretary to deal with. He wished to express to the members the very great regret of the President, Sir Thomas Holland, that he was unable to attend the meeting. Sir Thomas was the President also of the Institution of Mining and Metallurgy, and his Presidential Address to that Institution was fixed for that evening, thus accounting for his absence from the present meeting. One or two cards that he had recently received led him to say a word or two in regard to the versatility of some of the leading petroleum technologists. Not only was Sir Thomas Holland the President for the year of the Institution of Mining and Metallurgy, but Dr. Ormandy was President of the Institution of Automobile Engineers, while a Past-President, Professor J. S. S. Brame, was delivering the Howard Lectures on Motor Fuels before the Royal Society of Arts; and another of the members, Mr. O'Brien, delivered a lecture on oil refining on the previous evening. Every now and then he (the Chairman) liked to do a little blowing of the trumpet of the Institution in a mild way, consistent with professional etiquette and not in the way of advertising, but simply from the point of view of informing the members of the Institution how versatile some of its leading men were, the present speaker always excepted.

The paper that was to be read on "The Present Status of the Oil-Shale Industry in Estonia" was really a progress report, as a previous paper on the subject had been read before the Institution. The paper would, in the absence of the author, be read by Dr. Ormandy. He had asked Dr. Ormandy whether he was prepared to answer any questions that might be raised, and had received a reply in the affirmative, coupled with the intimation that Dr. Ormandy would not guarantee the quality of his answers. But, independently of Dr. Ormandy, there were present at the meeting Mr. Cunningham-Craig and one or two other gentlemen

who had first-hand knowledge of the subject which would supplement, Dr. Ormandy suggested, his lack of knowledge, although Dr. Ormandy was versatile enough to cover up any of his shortcomings in that respect.

Dr. W. R. Ormandy, before reading the paper, said the only excuse he had for occupying the chair of the reader of the paper was that he spent some very happy days with Mr. Kogerman in Paris, when they talked over the subject of the paper. He also had the pleasure of going over the paper with the author in its rough form some six months ago when he was in England, when Mr. Kogerman asked him whether he would read it for him, subject to the Publication Committee of the Institution being satisfied that the paper was suitable for discussion, Mr. Kogerman thinking that, having had some conversations with him, he would be able to deal with the subject better than a member who had not first-hand knowledge of it. The author also wished him to point out that in his position as a Government servant it was impossible for him, even in cases in which he had information bearing on the work of many of the private firms which was going on in Estonia, to make use of it, and therefore the paper was very largely a statement of what the Government were doing, supplemented with statistical information in regard to what the private firms were also carrying out.

Dr. Ormandy then read the following paper :—

The Present Status of the Oil-Shale Industry in Estonia.

By P. N. Kogerman, M.Sc. (Lond.), D.I.C., F.C.S., M.A.C.S. (Member).

Short History of Development.—The Estonian oil-shale, known as "*Kukersite*,"[1] was discovered by Engelhardt in the neighbourhood of Kohala 135 years ago, but it was only during the Great War that the importance of kukersite, as a substitute for coal and as a source of gas and oil production, came into prominence.

The idea of exploiting oil-shale as fuel for direct combustion was first brought forward by the late Russian Fuel Commission in Petrograd (now Leningrad) in 1916, when a shortage of fuel was being experienced in the Petrograd district. The Commission appointed a geologist, N. F. Pogrebov, to investigate the deposits of oil-shale and to estimate the supply available. In May, 1916, Pogrebov and his co-workers investigated the oil-shale deposits over an area of about 50 square kilometres along the Tallin (Reval)-

[1] The name "*Kukersite*" is derived from the village "Kukruse" in the vicinity of which F. Schmidt collected and investigated the fauna of the above-mentioned seams.

Petrograd railway line,[1] and a production of 2 tons of shale per square metre was estimated. Trials on a large scale, carried out at the Petrograd Gas Works, having given satisfactory results, it was decided to start mining operations at Kohtla for the production of 150,000 tons[2] of shale annually. The preliminary work in this mine had to be suspended in October, 1917, owing to the Bolshevist Revolution. During the German Occupation of Estonia, from February to November, 1918, the Germans also tried to exploit the oil-shale, and samples were sent to Berlin for analysis. In November, 1918, the Estonian Government took over the mine from the German authorities. Up to this date only the preliminary work, which consisted of drainage and the building of a railway line 2½ miles long to Kohtla Station, had been completed. A gravel pit about 50 metres long and 4-5 metres wide represented the whole mine, and the only equipment left by the German authorities was 3 locomotives and 60 dumping-cars.

The actual exploitation of oil-shale was started by the Estonian Government on May 5, 1919, and has continued since without interruption. For the working of the mine the "State Oil-Shale Industry," financed by the State, was established, and under this administration two mines are now working: the Kohtla Mine, open cut mining, and Kukruse Mine, with underground working system. The mines are situated 4-5 kilometres north of the Tallinn-Narva railway line, between the stations, Jõhvi and Kohtla. In addition to these mines a third one, the Vanamõisa Mine, which has lately been transferred to a private company, the "Estonian Oil-Shale Development Syndicate, Limited," working with British capital, was established.

Figure 1 shows the mining operations in the State Oil-Shale Mines. In 1922 a fourth mine, owned and managed by the "Eesti Kiviõli Company," started work at the station, Püssi. The Government has recently issued 23 permits for the prospecting for oil-shale.

The mining of oil-shale has made a rapid progress in the last four years, the annual production of the State mines being as follows:—

TABLE I.
OUTPUT OF OIL-SHALE IN THE STATE MINES.

Years.	Kohtla. M. Tons.	Kukruse. M. Tons.	Vanamõisa. M. Tons.	Total. M. Tons.
1918-1919	9,648	—	—	9,648
1920	45,844	—	281	46,125
1921	84,511	3,740	7,276	95,527
1922	127,410	11,522	—	138,932
1923	177,000	29,000	—	206,000
Total	445,000	45,000	7,557	497,000

[1] Approximately 100 miles east of Tallinn.
[2] Throughout this article "metric ton" is used

TABLE II.
OUTPUT OF PRIVATE COMPANIES.

	M. Tons.
Eesti Kiviõli Company in 1922	3,200
Eesti Kiviõli Company in 1923	6,600
Estonian Oil Development Syndicate in 1923 ..	3,340
Total	13,140

At present the State Works at Kohtla-Jaerve Mine own 21 locomotives and more than 600 dumping cars, the railway line is 25 miles long, and the colony consists of 66 dwelling houses and 332 tenements. In addition there are two distillation plants, power stations, work shops, lime kilns, storage rooms, etc. The old power station has a capacity of 75 kilowatts, and the new power station has a capacity of 500 kilowatts. The cost of the buildings[4] and equipment amount to 108,000,000 Estonian marks (approximately £67,500[5]) and the cost of materials and transport means, 58,000,000 Estonian marks (approximately £36,250).

There is also a post office, bank, school, hospital, and an efficient telephone system, etc. The "State Oil-Shale Industry" employs 25 chemists and engineers, 200 clerks and foremen, and 1,400 workmen. The output per head was 134 tons in 1923.

The total area excavated up to November 25th, 1923, was 310,411 square metres. At the Vanamõisa Mine an oil distillation plant with a pair of "Fusion" retorts has been erected. The company does not market the oil-shale, but uses it only for distillation at its own mine. The "Eesti Kiviõli" Company also is using the oil-shale for distillation purposes. The above-mentioned companies employ 200-300 workmen. The mining is carried out on the same system as in the Kohtla Mine. The soil and glacial deposits are usually removed by a steam shovel (excavator), being transported by electrically driven conveyors to the places where mining operations have been completed. Operating in this way, the exploited land can be transformed again into ground suitable for cultivation.

The Estonian oil-shale, which is one of the richest known, has attracted the interest of several foreign countries and many reports about it have been published, but so far the reports which have appeared have been neither up to date nor complete.

The Estonian oil-shale is not a new subject for this Institution, a brief account of it having been given by E. H. Cunningham-Craig.[6] Since then more experimental work, both industrial and research, has been carried out.

[4] The buildings are most of limestone, which is obtainable in the mines.
[5] The present rate of exchange is 1600—1700 E. marks to the £.
[6] "Kukkersite, the Oil-Shale of Esthonia," *Journ. Inst. Petr. Techn.*, VIII., 32, pp. 349-375, July, 1922.

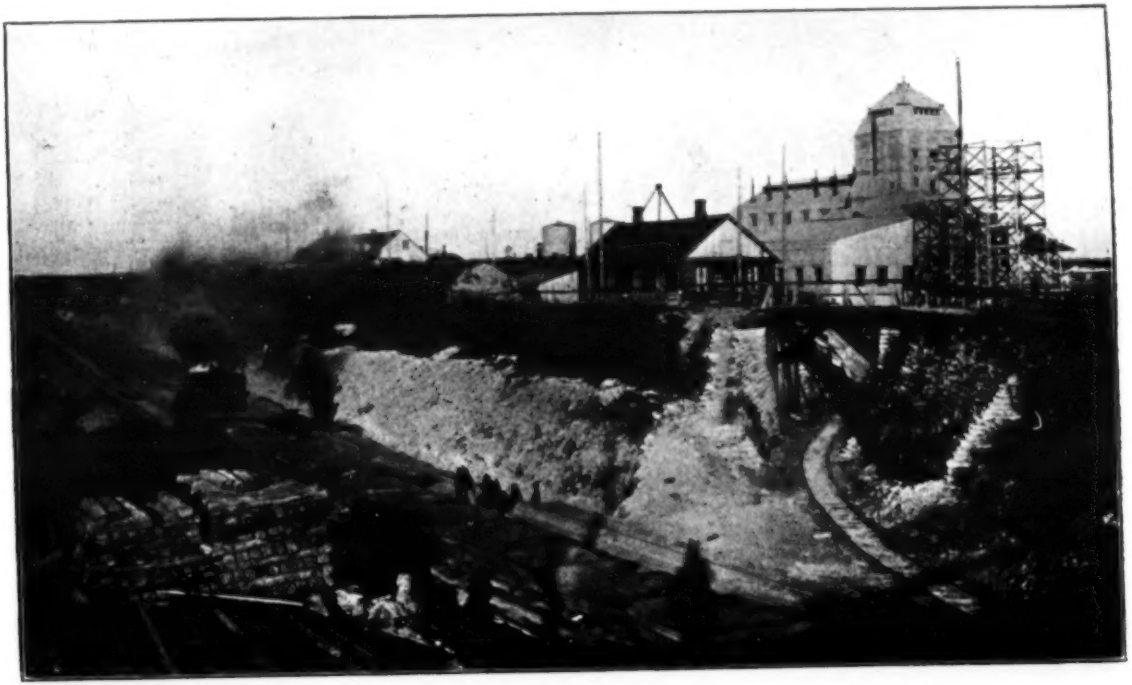


FIG. 1.

THE STATE OIL SHALE MINE AT KOHTLA

FIG. 2.
A SECTION OF KOMTLA MINE.

The Geological Structure and Properties of the Oil-Shale.—It is not the intention of the author to deal to any extent in this article with the geology of the oil-shale. This was recently reviewed by Dr. H. Bekker, Assistant Professor of Geology at the University of Tartu, Estonia, in his articles, "The Kuckers Stage of the Ordovician Rocks of N.E. Estonia" (Acta et Comment. Universit. Dorpatensis A., II., i., 1921) and "Stratigraphical and Paleontological Supplements on the Kukruse Stage of the Ordovician Rocks of Eesti (Estonia)" (Acta et Comment. Universit. Dorpatensis A., VI., 1924).

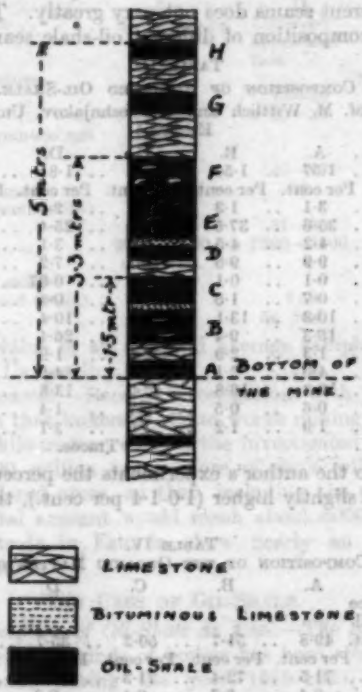


FIG. 3.

TYPICAL SECTION OF KOHTLA MINE.

FIG. 2.

A SECTION OF KOHTLA MINE.

The previous Russian and German reports, on which nearly all the articles which have appeared outside Estonia are based, are not up to date, some of the material being even incorrect.

The shale deposits occur in the Middle Ordovician Strata,[1] the whole formation attaining a total average thickness of 2·4 metres. The oil-shale seams are interstratified by lime-stone beds. The bedding of these seams is nearly horizontal with a slight dip (0·11′-0·13′) to the south and south-west. [Fig. 2.]

Fig. 3 shows the typical section of the Kohtla Mine.—The colour of the oil-shale varies from greenish-yellow to reddish. Air dried pulverised shale from the seams A and B looks very much like cocoa-powder. The freshly mined oil-shale is hard, only the weathered shale is soft and brittle. The hardness of oil-shale exceeds that of coal. The chemical composition of the organic matter in different seams does not vary greatly. Table III. shows the chemical composition of different oil-shale seams :—

TABLE III.

COMPOSITION OF AIR-DRIED OIL-SHALE.

(Analysis by Prof. M. Wittlich and N. Veshnjakov, University of Tartu, Estonia.)

Seams	A.	B.	C.	D.	E.	F.
Sp. gr.	1·57	1·56	1·61	1·81	1·54	1·65
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
H_2O	3·1	1·3	2·7	2·1	2·5	2·3
C	35·6	37·5	35·8	25·4	37·4	34·1
H	4·2	4·5	4·2	3·1	4·4	4·1
O	9·9	9·6	10·1	7·2	9·6	9·2
N	0·1	0·1	0·1	0·07	0·1	0·1
S	0·7	1·5	0·6	0·4	0·6	0·5
CO_2	10·3	13·1	8·6	10·4	9·4	12·3
SiO_2	15·3	9·4	18·0	26·4	14·7	14·4
Fe_2O_3	1·3	2·9	2·0	1·9	1·8	2·0
Al_2O_3	4·0	2·1	4·0	4·6	4·1	3·5
CaO	13·3	16·6	11·9	13·8	12·6	15·6
MgO	0·6	0·5	0·9	1·4	0·7	0·6
Na_2OK_2O	1·9	1·2	1·0	3·1	2·3	2·0
P_2O_5	Traces.					

According to the author's experiments the percentage of sulphur in all seams is slightly higher (1·0-1·4 per cent.), than given in the above table.

TABLE IV.

CHEMICAL COMPOSITION OF THE ORGANIC MATTER OF OIL-SHALE.

	A.	B.	C.	D	E.	F.
Organic substance of air-dried oil-shale, per cent.	49·8	51·7	50·2	35·7	51·5	47·5
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
C	71·5	72·4	71·3	71·1	72·4	71·6
H	8·4	8·7	8·4	8·6	8·5	8·6
O	19·9	18·7	20·1	20·0	18·9	19·6
N	0·2	0·2	0·2	0·3	0·2	0·2

[1] Dr. H. Bekker writes as follows: If the development of the forms in Estonia has proceeded on parallel lines to those in Great Britain, the kukruse stage would appear to lie about midway between the lower Llandeilo lime-stones and the lower Caradoc beds. They would probably therefore be slightly earlier than the *Nemagraptus gracilis* beds.

TABLE V.

COKING (CRUCIBLE) TEST OF OIL-SHALE.

Seams	A.	B.	C.	D.	E.	F.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Volatile subst. ..	56·7	60·1	54·2	42·7	56·6	50·4
Coke	4·8	2·9	6·4	4·3	7·4	9·7
Ash	38·5	37·0	39·4	53·0	36·0	39·9

The State oil-shale mines are marketing the oil-shale in three different qualities, which are described as follows:—

TABLE VI.

QUALITIES OF MARKETABLE OIL-SHALE.
(Analysis Kohtla Laboratory.)

Quality	I.	II.	III.
Description of shale	Sieved lumps.	Unsieved lumps and fine.	Fine, soil-like oil-shale.
Percentage of moisture—			
In summer	13—18	15—20	15—25
In winter	18—25	20—30	20—30
Percentage of ash/mineral ash plus CO_2—			
In raw oil shale	37—43	39—47	42—51
In the dry substance ..	50	55	60
Percentage of combustible substance	38—44	31—39	28—34
Calorific value	3000—3500 cals./kilo.	2300—2700	2200—2400
Price f.o.r. at the mine—			
In E. Mk. per pood (36lb.)	10	7 50	5·00
Per ton	7s. 9d.	5s. 10d.	3s. 10½d.

The calorific value of an air-dried average sample is 4400 cals./kilo (9900 B.Th.Us. per lb.).

Oil-Shale Resources.—Recent investigation with diamond drill bores has shown that kukersite strata worth mining cover an area of 1900 square kilo-metres, so that the investigated shale reserves amounts to 3800 million tons. More oil-shale will certainly be found in unexplored areas, so that, including the probable shale reserves, the total amount would reach about 5000 million tons. The oil-shale strata in Estonia show nearly an uninterrupted geological structure.

THE USES OF OIL-SHALE.

1. *The Consumption of Oil-Shale as Fuel.*—The consumption of oil-shale as fuel for all kinds of boilers has been steadily growing. Experiments made during the year 1919–1920, showed that furnaces, with fire grates constructed for the burning of coal or wood, were not suitable for burning raw oil-shale and therefore furnaces of a special, semi-producer type, have been constructed. At present several large factories in Estonia have had their boilers fitted with special fire grates and are using oil-shale for power production. Oil shale is the cheapest fuel available in Estonia.

Results of a trial of a water tube boiler with 143 sq. metres heating surface fired by oil-shale.

At R. Mayer's factory, Tallinn, September 18 and 19, 1922. The shale was burnt in an ordinary fire grate, constructed for burning peat and wood.

During this trial 40 cu. ft. of wood and 770 poods[1] of oil-shale (in lumps) was consumed. The cost of the fuel consumed in 24 hours was 9215 E.Mks. To raise the same amount of steam, firing by peat, the cost of the fuel amounted to 19,600 E.Mks., and firing by wood, 17,200 E.Mks. A pressure of 12 atmospheres was maintained in the boiler during this trial.

The combustion of oil-shale was not complete and a black smoke arose from the chimney.

The State Railway have partially adopted oil-shale as fuel for locomotives. Of the locomotives owned by the State thirty-five are heated with oil-shale.

In February, 1924, the Ministry of Communications appointed a Committee to inquire into the fuel problem of the State Railways. After investigation a final report was drawn up and accepted by the Committee on October 23, 1924, which may be summarised as follows:—

"At the present cost of fuels, oil-shale is the cheapest. If employed instead of coal in the heating of locomotives, there is an economy of 22 per cent., and if employed instead of wood the economy is much greater, amounting to 43 per cent.

2. At the oil-shale mines, oil-shale can be used for burning lime in kilns and for heating of houses.

3. The biggest consumers of oil-shale have so far been the Portland Cement factories. The cement works, Port Kunda and Aseri (Asserin), are using the cheap oil-shale of the third quality. The oil-shale is dried, pulverised and injected (by air), into revolving kilns. The oil-shale ash remains as an ingredient part of cement clinkers. The quality of the cement is the same as obtained by the using of coal.

4. *Oil-Shale consumed for the Production of Gas.*—The gas plants at Tartu (Dorpat) and Tallinn have only partially adopted oil-shale for gas production. The oil-shale is carbonised in old type, horizontal retorts, which, of course, are not quite suitable for the carbonisation of shale. The yield of gas is 10,000 cu. ft. (283 m³)

[1] One pood = 16·4 kgr.

per ton of shale, the yield of tar 4–5 per cent. The chemical composition of the gas is given as below:—

TABLE VII.

CHEMICAL COMPOSITION OF OIL-SHALE GAS.

	Per cent.
Hydrogen	37·6
Methene	25·8
Heavy hydrocarbons	1·6
Carbon monoxide	19·1
Carbon dioxide	13·3
Nitrogen	2·6

Calorific value of the gas 4200–4500 cals. per cu. metre. The use of coal for gas plants is preferred mainly for two reasons: (1) to obtain the extremely valuable by-product—coke, and (2) to avoid the cost of ash removal.

The Use of Ash.—The ash remaining from oil-shale after carbonization and burning is finely ground and has the properties of Roman cement; it is used as a binding material for building purposes. Table VIII shows the composition of the ash:—

TABLE VIII.

RANGE OF COMPOSITION OF ASH.

	Per cent.
CaO	26—50
SiO_2	27—51
Al_2O_3, Fe_2O_3	12—17
MgO	1·5—3
K_2O, Na_2O	3—6
S	0·5—3

THE DISTILLATION OF KUKERSITE FOR THE PRODUCTION OF OIL.

The production of oil from the shale is the most important of its uses. This main branch of oil-shale industry has a world-wide importance and is a most difficult problem to deal with.

I. LABORATORY EXPERIMENTS.

It is well known that the character of the yield of liquid distillates from a given fuel varies greatly, being dependent upon the temperature and manner of distillation. In all earlier investigations of kukersite no exact information is given as to the temperature of distillation or the method of operation. Some of the divergences in the results of distillations evident in the reports can be avoided by using standard methods of distillation.

During the years 1919-1920 the author carried out a series of experiments at the Fuel Laboratories, Imperial College, South Kensington. The method of operation is described in an article, "The Chemical Composition of the Estonian M.-Ordovician Oil-Bearing Mineral 'Kukersite'" (Acta et Comment. Universit.

Dorpatensis A., III., 6). The results[9] of first series of experiments are given below:—

TABLE IX.

DISTILLATION OF OIL-SHALE AT VARIOUS TEMPERATURES.

Temp. °C.	Percentage yield.	Yield of oil Galls. per ton.	Yield of gas cu. ft. per ton at 0° and 760 mm.	Yield of ammonia.	Calorific value of oils in B.Th.U.
410	27·1	63·3	1900	—	—
500	29·7	72·9	2250	—	17,028
600	30·8	74·8	3000	0·02	17,428
700	27·5	65·0	4500	0·04	—
900	21·7	49·7	7200	0·11	—

The yield of the oil is also dependent upon the weathering of raw oil-shale. Table X shows the results of distillation of four different samples of oil-shale.

TABLE X.

RESULTS OF DISTILLATION OF OIL-SHALE, FROM SEAM B (KOHTLA), SHOWING THE EFFECT OF WEATHERING UPON THE YIELD OF OIL.

(Analysis by Kohtla Laboratory.)

	Unweathered. Moist. Per cent.	Unweathered. Dry. Per cent.	Weathered. Slightly. Per cent.	Weathered. Strongly. Per cent.
Analysis of the shale—				
CO_2	12·6	12·6	10·4	6·6
Ash	38·9	38·9	33·7	46·8
Organic matter	48·5	48·5	55·9	46·6
Distillation—				
Oil	34·1	33·0	33·2	21·3
H_2O	2·2	3·5	4·5	5·0
Coke	55·7	56·4	54·1	65·2
Gas (by difference)	8·0	7·1	8·2	8·5
Specific gravity of oil	0·923	0·912	0·923	0·922
Analysis of coke—				
CO_2	21·5	21·2	18·4	10·1
Ash	68·2	68·3	61·9	71·3
Organic matter	10·5	10·5	19·7	18·6
The coefficient of utilisation of organic matter—				
Oil	70·3	68·0	59·4	45·7
Water	4·5	7·2	8·0	10·7
Coke	11·8	12·6	19·1	26·0
Gas	16·5	14·6	14·5	18·2
	103·1	102·4	101·0	100·6
Per cent. of unsaturated compounds	—	83·0	77·0	69·0

The distillation tests were carried out in F. Fischer's aluminium apparatus.

The results given in Table X show that the yield of oil from weathered shale is lower than from the unweathered.

[9] The results, calculated on dry oil-shale.

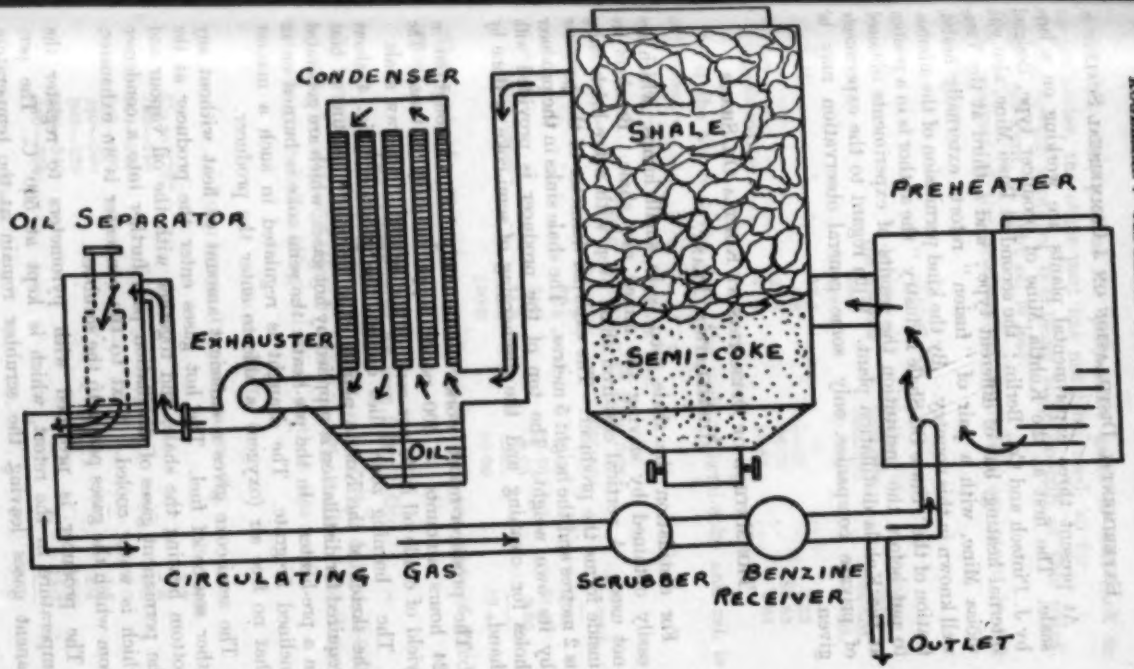


FIG. 4.

SCHEME OF THE KOHTLA EXPERIMENTAL OIL-SHALE DISTILLATION PLANT.

Experimental Distillation on a Commercial Scale.

At present three experimental plants are working on a large scale. The first at the Kohtla Mine of producer type, designed by J. Pintsch and Co., Berlin; the second at Pussi Mine, also with internal heating, but of different type; and a third at the Vanamõisa Mine, with a pair of "fusion" retorts externally heated, well known in this country. By the kind permission of the administration of the "State Oil-Shale Industry" the author is in a position to put before the Institution the results of experiments obtained at the Kohtla distillation plant. With regard to the experiments of private companies, only some general observation may be given.

The Method of Operation at Kohtla Oil-Shale Distillation Plant.

For distillation the shale used is in small lumps, which are easily obtained by sieving the mined raw shale. Breakers are not used. A vertical cast-iron shaft oven with a fire-brick lining inside forms the producer. The external diameter of the producer is 2 metres and the height 5 metres. The shale sinks in the producer by its own weight. The top of the producer is provided with holes for cleaning and the discharging of semi-coke is done by hand.

The producer-retort works continuously. The throughput in 24 hours amounts to 500 poods (approximately 8 tons). The yield of crude oil is 20 per cent. of the weight of the raw shale.

The "burning zone" lies outside the producer (Fig. 4 shows the sketch of the Kohtla plant). The necessary amount of heat required for distillation is supplied by hot gases, which are generated in a pre-heater. In the pre-heater the semi-coke is burned on an inclined firegrate. The draught is regulated in such a manner that no free air (oxygen) is able to enter the producer.

The semi-coke gives a sufficient amount of heat without any other source of fuel. The hot gases enter the producer at the bottom heating the shale, and together with the oil vapour and the permanent gases of distillation pass further into a condenser which is water cooled. Next to the condenser is an exhauster, from which the gases pass into the scrubber.

The producer is provided with pyrometers to register the temperature in the retort, which is kept at 500° C. The permanent gases leaving the scrubber remain at the temperature

of 65-70° C. One part of the permanent gases is sent back in the pre-heater, the other part has not been used so far.

Owing to the scrubber not being large enough at this plant, about 2 per cent. of light oil is lost.

The analysis of the products of distillation are given in the Table XI:—

TABLE XI.

	Analysis of the oil-shale used. Per cent.	Analysis of semi-coke obtained. Per cent.	Analysis of ash obtained. Per cent.
H_2O	13·8	—	—
CO_2	9·8	15·81	3·33
Ash	34·8	68·38	89·83
Organic matter	41·6	15·81	6·84

From the above given data, the yield of semi-coke and ash is as follows:—

TABLE XII.

YIELD OF SEMI-COKE AND ASH.

	Per cent.	Per cent.	Per cent.
H_2O	13·8	—	—
CO_2	9·8	8·05	0·98
Ash	34·8	34·80	34·80
Organic matter	41·6	8·05	2·65
	100·0	50·90	38·43

The semi-coke contains on an average 15-17 per cent. of fixed carbon.

THE PROPERTIES OF THE CRUDE OIL.

Sp. gravity of crude oil (with 1 per cent. of H_2O only) is 1·009 at 15° C. viscosity—5·5 (Engler) at 50° C. The results of distillation tests are given below (Engler-Levin's method was used).

TABLE XIII.

DISTILLATION TEST OF CRUDE OIL.

	Per cent.
Up to 220°	1·2
220—240	2·2
240—260	5·3
260—280	6·5
280—300	5·4
300—320	6·4
320—340	10·0
340—360	13·7
Total	50·7

Professor A. Franks, of the Colorado School of Mines, compared the properties of Scottish and Estonian shale-oils, and the results he obtained are given below:—

TABLE XIV.

COMPARATIVE DISTILLATE IN TESTS.

Scottish. Sp. gr. at 25° C., 0·864.				Estonian. Sp. gr. at 25° C., 0·937.			
Yield. Per cent.	Temp. °C.	Sp. gr. 25° C.	Saturation. Per cent.	Yield. Per cent.	Temp. °C.	Sp. gr. 25° C.	Saturation. Per cent.
1st Drop	85	—	—	1st drop	66	—	—
5	173	0·775	68·4	5	135	—	—
10	196	—	—	10	154	0·761	54·0
20	227	0·806	65·0	20	207	0·823	46·0
30	261	0·825	64·0	30	257	0·876	38·6
40	292	0·846	60·0	40	279	0·928	28·3
50	314	0·857	62·4	50	330	0·966	13·0
60	344	0·867	60·0	60	348	0·977	8·0
70	360	0·870	58·0	70	365	—	12·0
80	365	0·873	58·0	80	375	0·967	9·0
90	373	0·878	56·0	Coke 6·3 per cent. by weight.			
96·6	—	0·880	53·0				

The ultimate composition of oil is as follows:—C-81·26 per cent., H-10·15 per cent., O-7·26 per cent., S-1·08 per cent., and N-0·25 per cent. The dry shale-oil contains:—

	Per cent.
Neutral bodies (chiefly hydrocarbons)	72·1
Phenols (higher)	22·4
Carboxylic acids	4·0
Bases	0·2
Loss	1·3

The Uses of the Crude Oil.—The Kohtla crude oil is used at present mainly as fuel oil, fractionation being carried out on a limited scale only. The light oil obtained by steam distillation at 100° C. is suitable for motor-cars. The next fraction up to 280-300° C. is "motor-oil" for oil engines, and the residue is a pitch "shale asphalt" of high quality. Chemical refining is not used.[10]

On the basis of the above-mentioned experimental achievements a large oil distillation plant with a battery of 6 retorts (of slightly different designs)[11] has been erected and will start operations shortly. The throughput of the new distillation plant is 200 tons of oil-shale in 24 hours, and the quantity of crude oil would amount to 40 tons daily.

Distillation in the "fusion" retorts yields a crude oil of sp.gr. 0·958/15°. The crude oil is less viscous than that obtained at the Kohtla distillation plant.

[10] The fraction 230—270° C. contains cresols and may be used as disinfectant.

[11] In the plant the producer-retort and pre-heater form one vertical unit.

Finally the crude oil, obtained at Püssi Plant, stands somewhat midway between the above-described crude-oils.

With regard to the "Eesti Kiviõli" Company distillation plant the author has to mention that the plant is working under management of highly qualified men. The research laboratory at Püssi Mine is well equipped, and many interesting results have been obtained.

Some Problems of the Future.—Up to the present the Oil-Shale Mines have chiefly supplied the home market with the solid and liquid fuel.

The consumption of oil-shale has been as follows:—

TABLE XV.

THE CONSUMPTION OF OIL-SHALE (In metric tons).

Consumers.	1918-19.	1920.	1921.	1922.	1923.	Total.
Portland cement factories	1,135	12,288	37,244	113,554	102,995	267,216
Railway	424	8,923	9,234	14,903	34,209	67,693
Fuel, gas factories and experiments ..	8,089	24,914	10,824	5,775	18,856	68,458
Kohtla experimental oil factory ..	—	—	981	2,202	3,200	6,383
Total	9,648	46,125	58,283	136,434	159,260	409,750

The annual fuel requirements in Estonia for oil-shale alone is given below:

TABLE XVI.

OIL-SHALE REQUIREMENTS IN ESTONIA.

	M. tons.
Portland cement work	170,000
Other factories	340,000
Railways	200,000
Small consumers	40,000
	750,000

From the Table XVI. above it follows that consumption of power in Estonia is very small indeed.

The oil-shale industry in Estonia must be developed on much broader lines. The favourable geographical position justifies the prediction of a prosperous future for the *shale-oil* industry in Estonia. At present the shale-oil is the cheapest crude oil in Estonia, and will be probably the cheapest oil in the North of Europe.

In the present distillatian operation on a large scale about 80 per cent. of the laboratory yield has been obtained, but there is another problem to be solved in the near future to convert as big as possible a portion of the crude oil into light oils, for which there exists a great demand on the world market.

Finally, it must be borne in mind that the oil-shale industry is not "a poor man's game." Only when properly organised and financed will desirable results be obtained.

DISCUSSION.

The Chairman, in moving a very hearty vote of thanks to the author for his interesting paper, and to Dr. Ormandy for his kindness in reading it, said he was sure the members would agree they were indebted to the author for bringing their knowledge of the subject a little more up to date, and to Dr. Ormandy, not merely for the trouble he had taken in reading the paper, but for the way in which he had emphasised important points and elucidated some of the tables. The paper was perhaps more interesting at the present moment on its economic side than it was on the strictly technical side, *i.e.*, from an oil point of view. He thought that every good oil man who believed in the present and the future of natural petroleum oil nevertheless was always casting his eye to windward to see what was happening in regard to shale. No doubt many of the members received the interesting journal that was published by the Colorado School of Mines, and it was apparent that Colorado in particular was watching European developments in regard to shale oil. As all the experts knew, the question of the retorting was one of very great importance. He recalled meeting a few years ago a gentleman from Wyoming who was searching Europe for various types of good retorts to apply to the shale of that district; while at the same time a company with which he (the Chairman) had some association was employing an American type of retorting to shale in Canada. A great deal yet remained to be learned in regard to the types of retorts that were suitable for varying conditions of oil. He believed their Scotch friends knew quite well that the Scotch system was not applicable to all kinds of shale. He had been trying, from the economic side, to make a few rough calculations in regard to the figures given in the paper as to the resources of oil-shale available in Estonia. From the estimate given it appeared as if there might be something like 1,000 million tons of shale-oil potentially producible in that region. That figure was worked out on the basis of the 5,000 million tons of shale mentioned. From the figures given it appeared that the estimate of the yield of shale per square metre was not quite up to the figure of 2 to 1 mentioned in the paper. It would be noted that 310,000 square metres of excavation yielded 510,000 tons of shale, which was not quite in the ratio of 2 to 1. The paper indicated that not very much oil had yet been produced from Estonian shale, and the members would therefore look forward with great interest to further reports in regard to the behaviour of the plants described. He would also be interested to know whether the use of shale in a pulverised form for cement-making described in the paper was the first big experiment that had been made in that way. Most of the members

knew that bituminous coals in a pulverised form were sprayed into cement furnaces, and the ash and the other ingredients were taken up in the cement. He knew that was carried out in this country and also on a large scale in America. It would also be most interesting if it were possible to obtain information in regard to how the use of shale (for other purposes than cement-making) in the direct form in which coal was used, compared from an economical point of view with what might be expected from the various products of shale when more shale oil was produced and fractionated in the usual way.

Mr. E. H. Cunningham-Craig, in seconding the resolution of thanks, thought that the new statistics which were contained in the paper would prove of great value. Although perhaps there was nothing in the paper which was very new, the information was up to date. Several points that had been emphasised might appear rather surprising to people who did not know anything about that wonderful deposit Kukersite. He thought it ought to be called Kukersite and not shale, because it was so very different from almost every other oil-shale; it was so much richer and in some ways it was so much more difficult to deal with. For instance, taking its chemical composition, it showed a considerable variation, which was almost entirely due to the varying amounts of lime which occurred almost without exception as broken shell. That caused a difference in yield of oil and in chemical composition. If that lime was eliminated, as practically all of it could be, because it was broken shell fragments and not belonging to the matrix, it would be seen that the composition of the inorganic portion was a fuller's earth. It would be seen also that the composition of the organic portion was that of quite a heavy oil, and the amount of oxygen in it showed how highly it had been inspissated before it had been adsorbed. There were some points mentioned in the paper which, if they were not fully understood, would, he thought, do the industry a great deal of harm. For instance, the statement was made in the Government Report that the yield of oil was 20 per cent., whereas it was quite easy to get a yield of 25 per cent. The specific gravity of the oil made in the vertical retorts was greater than unity, 1·009; the petrol content was practically nil; and there was fixed carbon in the semi-coke up to 15–17 per cent. All those figures absolutely condemned the system of retorting adopted. It would be noted that in the investigations carried out by the Colorado School of Mines a specific gravity of 0·937 was obtained. Even that was not very good, but they obtained some 15 per cent. of petrol up to a temperature of 154° C. The work of the Estonian Oil Development Syndicate had proved that it was possible to get an oil of between

0·92 and 0·93 specific gravity. The worst oil that the Estonian Development Syndicate had made up to date had a specific gravity of 0·95; they could make an oil with a petrol content of about 17 per cent., and he thought they could get a little better than that. The reason was that the material must be dealt with at a fairly low temperature. The oil came off very rapidly and the material passed through a very sticky stage. It was impossible to feed fines into a vertical retort; only lumps must be used; and the workmen could be seen digging away with steel rods into the top of the retort to try to get the material to go through. The result was that a yield of 20 per cent. instead of about 25 per cent. was obtained, and a disgracefully poor oil was produced. It was unfortunate that the author had not supplied details, which might have been given, of the work done by the other companies, because to publish figures showing an oil with a specific gravity greater than unity (in spite of which it could be sold in Estonia for about £4 10s. a ton), might lead people to think that nothing better could be done. He considered that the Kukersite of Estonia was one of the greatest assets that Northern Europe possessed, but in view of the figures given in the paper that great asset was made to appear of very much less value. On the other hand, if a good low temperature process were employed in which all the fines and all the lumps were used, a really valuable oil could be made in very much greater quantities than was being produced by the Government retorts.

Sir Philip Dawson, M.P., said he spoke with some hesitation at such a meeting of experts. He was in no manner an oil expert, or a chemist, or one who from that point of view was able to give any information to the members of the Institution, whose knowledge of the subject of oil, no matter from whence it was derived, was so thorough and complete. But being an engineer by training, being interested in business, having had the privilege of visiting on more than one occasion the very interesting country of Estonia, having had the opportunity of admiring the energy and the ability of the people, and having, also, the privilege of knowing the author, whom he met at the end of last January when he was in Reval, he hoped he would be forgiven if he made a few general remarks on the subject of Estonian Kukersite. He particularly desired to call the article Kukersite and not oil-shale, because as far as this country, at any rate, was concerned, those who had had the misfortune to try to do something with shale had burned their fingers, and oil-shale as a consequence had received a very bad name indeed. He would not go into the causes which brought about that very bad reputation, or refer to the various things which had been said about it in the past For that reason he

was very glad that Mr. Cunningham-Craig had so clearly explained the great difference that existed between the deposits in Estonia and the deposits which were called oil-shale in this country. He desired to add a few remarks in regard to the investigations which had been carried out by the independent experts of other nations besides our own in connection with Estonian Kukersite. He had had several interesting conversations with the principal engineers of the Deutsche Continentale Gas Gesellschaft, a firm well known to most of those present; and he thought everybody would agree that, whatever other characteristics the Germans might or might not possess, they had the characteristic of most thoroughly investigating any problem which was put before them. The principal engineers and the managing-director of the Deutsche Continentale Gas Gesellschaft told him before he went to Estonia at the beginning of January, and when he came back from Estonia at the beginning of February of the present year, that they had carried out very thorough and complete investigations in regard to the value to be attributed to the Estonian deposits, and that they were so interested in the subject that they had had 300 tons of the material taken to Germany and tested in retorts, and as a result they had formed the very highest opinion of the great value of the deposits in that country. As a matter of fact they made him a definite offer that they would put up a plant and would guarantee that 25 per cent. of the weight of dry Kukersite would be produced in oil. They were prepared to carry out that guarantee on the basis that if that result was not achieved they would take the plant back and return the money which had been paid for it. That was an indication of the high opinion that that very eminent firm had arrived at in regard to the Estonian deposits, an opinion which they had backed by a very considerable expenditure of money. Another firm of German financiers, headed by the very well-known banking house of Von Mendelssohn, whose representatives were men of very great ability, informed him that they had already spent over £100,000 in practical experiments on the plant in Estonia; that they were satisfied that real commercial results could be achieved, and that they were preparing to spend a very much larger amount of money on the practical development of the fields. He also met the representatives of Messrs. Wallenberg, one of the most important financial houses in Sweden, who were intimately connected with and who operated in connection with all the big banking groups throughout Europe and America, and ascertained that they had been investigating the subject for several years past. They had employed the best Swedish experts; they had taken to Sweden very large quantities of Kukersite for testing purposes; and as a result of their experiments they had

now taken up, as was stated in the paper, very large properties in Estonia and had given the Government guarantees (which coming from such a quarter could be relied upon as satisfactory) that they were prepared to spend very large sums of money in the practical development of those fields. He hoped that this country would be as progressive in the future as it had been in the past. Its inventive abilities had not been surpassed in any other part of the world. Its chemists made aniline dyes possible, but they were unfortunately prophets who were not recognised in their own country. At that time they were looked down upon, with the result that their inventions were taken up and developed in Germany, with the consequence that when the Great War came this country was in a most unhappy and unfortunate position in regard to the great dye industry which the genius of its people had made possible of development. For that reason he was glad the present paper had been read, and he hoped the efforts of those very energetic people who had spent a very considerable amount of money on the property at Vanamoisa would be continued and would be crowned with success. The results achieved there had been mentioned by Mr. Cunningham-Craig. There were some very efficient Englishmen on the spot, and he trusted that the people of this country would assist those Englishmen to develop that property, to put money into it, which should be spent entirely on the development of the property and thus render available for the Royal and mercantile navies those great oil resources which nobody could possibly doubt existed in Estonia.

Mr. Stainer Hutchins said that as he happened to be the inventor of the fusion retort several of the remarks made by Dr. Ormandy in reading the paper had proved of great interest to him, particularly the different yields resulting from weathered bituminous material compared with freshly mined material. That difference appeared, not only in Estonian shales, but in other bituminous materials, although why the difference occurred was not fully known. One loss that occurred in weathered bituminous material was the evaporation of the light oils, which was distinctly marked in fuels which came over the Equator and probably fuels transported under other conditions. It would be of interest to obtain from those who were in a position to get samples of Estonian shale and test them the whole of the factors connected with the shale, namely, an analysis of the gas, the calorific value of the gas, the yield of oil, specific gravity of the oil, the percentage of residue and an analysis of the residue. One factor mentioned by the author in his paper was of great importance, namely, the presence of lime. If Estonian shale was heated to a temperature of 950° C. for the purpose of obtaining the volatiles, not only would CO_2

be given off but also CO, and this would and probably had caused confusion and incorrect conclusions.

He hoped that some of the rather misleading points in the paper would eventually be cleared up, particularly the remarks made in regard to the oil yield. It was not only a question of the actual yield of oil but the quality of the oil, because on its quality depended the possibility of refining. Certain oils could be easily refined, whereas it was almost impossible to refine others, or at any rate the process was a very expensive one. The difficulty in regard to black smoke referred to in the paper could be overcome in practice; it was only a question of secondary air.

Mr. R. Mollerson (Consul-General, Estonia) said it was very difficult for him to address such a learned audience on a question in regard to which he was only a superficial observer. He was able to say, however, that great progress had been made in the development of the new industry in Estonia to which the paper referred. He desired to thank the pioneers who had been mentioned for the enterprise and energy they had displayed in that connection. The Estonian Government had also displayed great energy in the same direction and spent much money in the making of various preliminary tests. The question was really one of necessity. In view of the Great War it was impossible for Estonia to obtain regular supplies of fuel from outside, and it was necessary to find some substitute. For that reason such great energy had been devoted to the development of the oil-shale of the country. The preliminary investigations which had been carried out had led the Government to believe in its commercial possibilities, and various groups from different countries had already started practical investigations and practical work on a small scale. He desired to congratulate the English group on the energy and enterprise they had shown in developing the particular concessions they had received. There was strong competition on the part of other countries, but speaking on behalf of the Estonian Government he wished to say they would be delighted to see greater interest displayed by British capital in the exploitation of the resources of Estonia. Estonia had a great admiration for British institutions and Great Britain generally, because it owed very much to Great Britain, and that was why the country would like to see British capital and British commercial people taking an active interest in its development.

Dr. Lessing said that he believed, in connection with Table X, which referred to the unweathered and weathered shale, that the figures given had already been reduced to the dry process, because it would be noticed that the amount of water given for the moist specimen was actually lower than for the dry one. The question

of weathering to which allusion had been made was a very important one, and he believed that it was mainly due to oxidation. It was known that coal and all bituminous materials were very liable to oxidation. In the case of the Estonian deposit oxidation could act more readily on account of the large amount of inorganic mineral substance it contained. Sir Philip Dawson had mentioned that he refused to call the material oil-shale; he thought Sir Philip was perfectly right in that remark. It was rather a pity that the term had been used in connection with it. The analysis of the inorganic mineral portion of the deposit showed that it was certainly not clay, but that the preponderant constituent was limestone. Mr. Stainer Hutchins had already pointed to pitfalls in the estimation of volatile matter; if the volatile matter test was carried out at the customary temperature of 900° or 950°, the limestone was calcined and the carbonic acid from the limestone was included in the volatile matter. That was a possible analytical error which influenced the interpretation of any analyses made of the material. A very much more important point was the composition of the mineral matter in relation to the distillation of the organic constituents. It had been found that the composition of the mineral matter in coal and in any organic substance influenced the course of carbonisation, and of thermal decomposition generally, to a very large degree. It was therefore not surprising that in the experiments carried out by Franks in Colorado, which presumably were done under absolutely comparable conditions, very different results were obtained from a Scotch shale and from the Estonian deposit. In the one case a true shale was being dealt with, and in the other case a limestone. The alkaline condition of the limestone basis influenced the thermal decomposition of the organic matter. Assuming for argument's sake the original organic matter to be the same in both deposits, but in the one case mixed up with a shale basis and in the other case with a limestone basis, different results would be produced in the working, both in regard to quantity and also quality. That was a very important fact from the technical point of view. He desired to express his appreciation of the work done by Mr. Kogerman. He did his work for his Government, and not for any commercial group; he looked at the whole problem in a scientific way and tried to form as unbiased an opinion as possible on the technical side.

Dr. W. R. Ormandy, in reply, said that unfortunately he was not in a position to answer all the remarks that had been made. With reference to the remarks of Mr. Cunningham-Craig, he desired to say, however, that he knew Mr. Kogerman was as conscious of the weakness of the system which was being used for the dis-

tillation of the shale as Mr. Cunningham-Craig was. Mr. Kogerman pointed out to him that the Estonian Government had charge of a comparatively poor and young country, which possessed very little money. They were faced with one hundred gentlemen from every part of the world who were perfectly willing to sell them retorts which they were convinced were perfect, but what they had to do was to obtain a retort which gave results. If the results were not the best that might be obtained, nevertheless they were results which paid, and they provided oil fuel which the country badly wanted. On the whole the Estonian Government had spent something like £100,000. The meeting had heard that various companies had spent £100,000 also, with very much less to show. They might eventually show more—they probably would; but it was the duty of the Estonian Government to produce with the least possible outlay of money some results in order to give a growing country that which it could not afford to buy from outside.

The resolution of thanks to Mr. Kogerman for his interesting paper, and to Dr. Ormandy for his kindness in reading it, was then put and carried unanimously, and the meeting terminated.

In a written reply, **Mr. P. N. Kogerman** said he desired to record his thanks to Dr. Ormandy for his kindness in reading the paper.

With reference to the Chairman's remarks, the yield of shale per sq. metre was not quite up to the figure of 2 to 1 mentioned in the paper. The ratio given has an approximate value and slight variations have been observed. The latest Government Report states that the actually investigated Kukersite reserves reach the amount of 5,500 million tons.

In reply to Mr. Cunningham-Craig, the author agrees that the mineral ought to be called Kukersite and not shale; and he pointed out the difference between Kukersite and an ordinary shale three years ago in a paper on the subject. The term "shale" was used merely for convenience.

With regard to the question of lime in the inorganic portion, that after removal of lime, which is broken shale fragments, it would be seen that the composition of the inorganic portion is a fuller's earth.

The whole lime is not in the form of broken shell fragments, but chiefly in the form of limestone; the composition of the inorganic portion is not identical with that of fuller's earth. Further, according to the author's researches, the chemical nature of Estonian shale-oil differs greatly from the composition of crude petroleum.

The author was surprised at reading Mr. Cunningham-Craig's opinion that, in view of the figures given in the paper, the great asset (Kukersite) was made to appear of very much less value. He (the author) regrets being misunderstood; but the facts in the

paper were given in very condensed form and the author assumed that the phenomena accompanying the thermal decomposition of oil shales (and Kukersite) are well known to the members of the Institution.

The method of retorting has a great effect upon the yield and character of oil. The distillation plant at Kohtla, described in the paper, is far from being an ideal one. An ideal distillation plant has not been designed so far. The statement that the oil produced at Kohtla experimental plant is disgracefully poor and the yield is low seems to be misleading. Mr. Cunningham-Craig has overlooked the author's remark that about 2 per cent. of light oil has been lost (a fact experimentally proved); by using "activated charcoal" an additional 3–4 per cent. of very light oil can be recovered; so the yield of oil is really 22 per cent.

In the first commercial distillation plant designed on the same principles (at Kohtla) an oil richer in light fractions is produced, but the sp. gr. of the oil is still high (about 0·96). The treatment of shale at "fairly low temperature" does not always produce an oil of sp. gr. 0·92 or 0·93.

The author takes the opportunity to refer to an important paper by R. H. McKee and R. T. Goodwin. [R. H. McKee and R. T. Goodwin: "A Chemical Examination of the Organic Matter in Oil Shales," Quart. Colo. School of Mines, Vol. 18, No. 1, Suppl. A (1923)]. The authors write as follows:—

"It is believed by many that the first pyrolysis products of oil shale are the light hydrocarbon oils corresponding to gasoline and kerosene in physical properties. The next product should be a still heavier oil, and so on, until the final distillation product would be heavy residuents, such as fuel oil and paraffin. In this investigation an intermediate product has been isolated. . . . This heavy solid or semi-solid bituminous material is decomposed by heating to form the hydrocarbons."

A true low-temperature oil, which contains both lower and higher boiling fractions, is comparatively heavy and viscous. Of course, in externally heated iron retorts (or distilling with superheated steam) at about 450° C. an oil of sp. gr. 0·91 could be produced, and the author himself found in one particular oil about 25 per cent. of light oils, but the yield of crude oil in such cases is much lower—in the case of Kukersite roughly 15 per cent. of the weight of dry shale. Our ideal is to reach the highest commercial efficiency without sacrificing the raw materials of the country. Mr. Craig has overlooked another important factor, the coefficient of utilisation of organic matter of Kukersite. At Kohtla plant, on an average, about 78 per cent. of the theoretical or laboratory yield (see Table IX.) has been obtained; whilst in the retorts, producing

a light crude oil, about 50 per cent. of the theory could be obtained. It seems to be a general rule that the lighter the crude shale-oil the lower the yield, and the smaller the portion of organic matter utilised.

An oil of sp. gr. 0·95 to 0·97 has been produced by the Pussi experimental plant, with a quite different type of retort. It is a fairy tale to state that there are at present means by which the whole organic substance of an oil-shale can be converted directly into light oils.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE EIGHTY-SIXTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the Royal Society of Arts on Tuesday, May 5, 1925, Sir Thomas Holland, K.C.S.I., K.C.I.E., D.Sc., F.R.S., President, occupying the chair.

The Secretary read the following list of those who had been elected members since the last Meeting.

Members.—Alan Meredith Edward Beavan, Jacques Iaroslavici, Sidney Powers, Hugh George Shatwell, Louis Weston.

Associate Members.—Douglas Leonard Alexander, John Alexander Buchanan, Joseph Reed Grove, George Alfred O'Neill, John Mellor Pattinson, Douglas Selwood Treble, Letham Kay White.

Transferred to Associate Member.—Herbert James Mason, James McAdam.

Students.—Richard James Hayman, Kenneth Chesterton Johnson, William Edmund Madden.

Associates.—Percival Hutchinson, Karel van Zonneveld.

The following paper was then read :—

Some Notes on Water Shut Off.

By F. G. RAPPOPORT, A.R.S.M., M.Inst. C.E., M.I.Mech.E., F.G.S. (Member).

INTRODUCTORY.

THIS paper lays no claim to originality, and has been prepared chiefly in order to initiate a discussion on this important subject in oil technology.

The problem of water shut off is one in which the engineer, geologist and chemist are all alike interested, and in which each can co-operate.

The importance of the subject is well known. In many fields, particularly the older fields before the water menace was clearly realised, rich upper sources are to-day flooded and useless for oil production.

It is now realised that this menace does not affect individual wells only, but the oilfield at large. Hence co-operation has been established among operators on oilfields, and the former tendency to secretiveness, with its damaging results, is largely disappearing. Governments have realised the necessity for united action, and have stepped in with legislation for enforcing the necessary conservation measures. One may cite such fields as Burma, Rumania, the Dutch East Indies, and the American fields where the Government watches this question.

As already stated the subject is of interest to the geologist, the chemist and the engineer, and this paper has been subdivided under these headings.

I. Geological.

There are two ways in which water and oil are related under natural conditions. In one, the water and oil lie separated at different horizons. In the other the two liquids are in the same horizon, but separated according to selective segregation, and are under pressure due to the head of water. These states may occur under different tectonic conditions, such as faulting or folding. In both cases there is thus equilibrium under natural conditions.

The drill, or the search for oil, tends to upset this state of equilibrium.

In the first case mentioned, the water strata are definitely separated from lower lying oil deposits by impervious beds. The latter may, of course, still be under water pressure from some distant source, or may be under pressure due to the movements that caused the folds. The point, however, in this particular case is that the water source above and the oil source beneath are originally separate.

In the second case, the water assists in displacing the top members of the sequence, gas and oil, and eventually takes their place. This is the case of bottom or edge water in an oilfield. It does not, however, follow that all the oil and gas are necessarily displaced to the surface, and become of economic utility. Mills has shown that water easily displaces oil from coarse sands, but with greater difficulty from fine sands. There is thus a possibility that, with the more rapid advance of such water, oil may be entrapped, or once again conserved underground by its own water, as it was in its initial state of equilibrium.

We thus distinguish the two chief subdivisions of water prevalence in an oilfield :—

(*a*) water in the oil source itself, and
(*b*) water in sources outside the oil source.

There are different cases of each of the above main types. Thus (*a*) can be further subdivided into what is known as true edge water, more particularly noticeable when the oil source has originally been free from water, or "bottom" water" that was in the source when first reached; or (*b*) can again be subdivided into water above the oil source—top water, or water between two oil sources—intermediate water, or again, water below the oil source, *i.e.*, separated by a larger or smaller impervious division—bottom water.

These two great subdivisions have their practical significance. Thus (*a*) or edge water cannot be radically dealt with for purposes of exclusion by mechanical means, as the encroachment of the water is in this case a natural process. Palliative measures, based on experience, are, however, possible either to prevent the entrapment of oil by the advancing waters, or the eventual exploitation of such entrapped oil; (*b*) on the other hand can be dealt with by mechanical means, and most of the invention and ingenuity applied to water shut off problems have been directed to this second great subdivision of water trouble, *i.e.*, the prevention of access of water (whether top, intermediate or bottom) to the oil sources.

In the Grosny field all the water bearing horizons are above the main oil sources. This is a typical instance of the first oil horizon being situated very near the lowest water source (see Diagram 2, Case V.). To deal with this presents difficulties in practice, as the impervious stratum intervening between the first oil and the last water source is too narrow for an effectual water shut off. This will be referred to again later in this paper.

Another interesting case from actual experience is that of the Maikop oilfield (Diagram 1). Here, again, there are four distinct water horizons. The two upper water horizons lie in the so-called "massive sands and clays with intrusions" situated between the two heavy oil horizons known respectively as the first or "the Neftyanaya wells horizon" and the second or "Shirvanskaya wells horizon." The lower parts of these two oil horizons are water bearing, and this is an example on this field of "Creeping" or "Edge" water. There is good reason to believe that the two water sources themselves, lying between these two oil horizons, are cases of edge water having finally invaded what formerly were two distinct oil horizons.

The two lower lying water horizons in this field are characterised, one by its sulphuretted hydrogen content, the second by containing much carbon dioxide.

Galicia is another good example of creep or edge water. There are three well defined oil horizons in this field, viz.: (1) the Boryslaw sandstone of the Lower Oligocene; (2) the Popiela sandstone of the Lower Eocene; and (3) the Variegated sandstone of the Lower Eocene. One at present has no water. Both two and three,

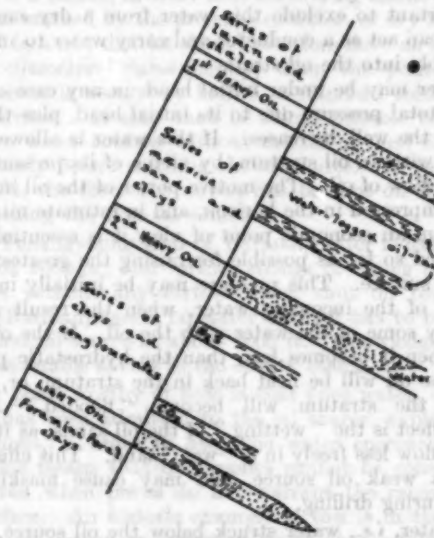


DIAGRAM I.

DIAGRAMMATIC SECTION OF MAIKOP.

following intensive production, have been invaded by edge water. The ingression was remarkably sudden and rapid about the year 1910. Those interested will read a good account of this occurrence in Mr. Albert Millar's paper read before this Institution in April, 1922.

Edge water encroaches up dip as oil and gas are withdrawn. Such encroachment is not necessarily regular, and depends upon such factors as the rate of withdrawal of the oil, the relative porosity of the different sands through which the water passes, the gas pressure, the hydrostatic pressure of the water, etc. One sees this clearly in the diagram of water encroachment in the Galician

field (see Paper above referred to), where water appears somewhat irregularly, but actually in a general way up the dip slope. Development tends to draw in edge water in accordance with physical laws. The judgment on edge water must be a careful one, as the appearance of such water usually marks the first stage in the exhaustion of a field.

A top water will follow the well in its drilling course, and if permitted to do so will come into contact with other porous beds, whether these are dry, oil or water bearing.

It is important to exclude this water from a dry sand also, as such a sand can act as a conductor and carry water to other wells, and so possibly into the oil strata.

A top water may be under initial head, in any case as the well deepens the total pressure due to its initial head, plus that due to the depth of the well, increases. If this water is allowed to come into contact with an oil stratum, by virtue of its pressure head, it acts on the inflow of oil. The motive power of the oil in the sands is the gas compressed in the horizon, and in intimate mixture with the oil. From an economic point of view it is essential that this energy be used so far as possible for raising the greatest quantity of oil to the surface. This pressure may be initially in excess of the pressure of the incoming water, when the result will be to raise uselessly some of the water with the oil. If the oil pressure is less, or when it becomes less, than the hydrostatic pressure of the water, the oil will be held back in the stratum, or, in oilfield phraseology, the stratum will become "flooded." A further deleterious effect is the "wetting" of the oil sands, as it is known that oil will flow less freely in a "wet" sand. This effect is more evident in a weak oil source, and may cause masking of the indications during drilling.

Bottom water, *i.e.*, water struck below the oil source, may also be under considerable hydrostatic head, and may rise in the well, and by its pressure flood an upper lying oil source. This may be difficult to deal with, especially if the water source is only separated from the oil by a thin stratum.

The location of bottom water is of great importance, in order that the upper lying oil source may be protected by natural conditions. Otherwise drilling into the bottom water may flood the oil source. Bottom water may erroneously be regarded as edge water in some cases.

Intermediate or middle water, occurring between two oil sources, is also a frequent cause of trouble, especially if the partings are thin. One way of dealing with such cases is to exhaust one sand and proceed to the second, allowing the first one to be flooded. Such a course of action would have to be taken in co-operation with the

rest of the operators. Other methods of dealing with this case will be referred to later.

It is desirable, in fact essential, to learn the geological conditions of a new district as soon as possible, in order to make the necessary provisions for dealing with water by a systematic system of casing for the purpose of adequately protecting the oil sources. Initially, this will have to be done by means of carefully drilled test wells. In such wells the sound policy is to shut off water soon after it is struck, in order that lower lying unknown oil sources may not be masked by the presence of water, or dry sands flooded. A test well in a new district should therefore have an ample reserve of casing diameter. Subsequently, when the position of water and oil sources is accurately known, a standard method of casing may be devised. It may then be found possible to carry down one or two water sources without detriment, and shut these off simultaneously before reaching the oil source. In the case of the Grosny field, the three top waters can be shut off simultaneously before reaching the first oil source.

In the Yenangyoung field of Burmah, water is usually shut off at or about 1000 ft., and further strings of casing carried to the oil sources without any further water shut off being required. In Singu (Burmah) again, no water shut off has to be made until near the first oil source at about 2000 ft. Knowledge of this kind means considerable saving in the cost of casing.

Another point worthy of note is that once water, even in small quantity, has been admitted to the oil source, exploitation must be continuous, in order to keep the water encroachment within limits. This means that oil supplies cannot be conserved underground, even when prices do not warrant the raising of the oil to the surface. An historic example of this is in the Baku field, where due to absent or defective water shut off in early days, water and oil had to be simultaneously extracted. After the political troubles in 1906, when the fields stood idle for several months during reparation of surface damage, the water gained so much headway that the field never recovered its former production from those oil sources.

Another evil attendant on the entrance of water, more particularly in the presence of gas, is the formation of an emulsified mixture of oil and water which is difficult to separate, and leads to considerable loss of oil.

Water may also be admitted to an oil source through defective casing. Badly plugged, abandoned wells are a frequent source of water trouble in oilfields, as such wells act as conductors of water into the oil sources.

It is evident that the correct distinction of the various types

of water is of essential importance, especially in the initial stages of testing and developing a new field.

In all that has been said one sees the importance of close co-operation among the workers on an oilfield, in respect of the exchange of accurate geological information of a new district, and of the results of test drilling. Conditions in this respect are much improved over what they were fifteen to twenty years ago.

II. Chemical.

Waters.—Chemical analyses of different waters struck in the progress of drilling a well help in the general determination of the position of these waters in a field. In the case when water has again been struck after a water shut off has been completed, it is important to know whether this ingress is due to the shut off being defective, or to another water source struck below, levels of the liquid may assist in forming a judgment, and finally direct tests by plugging the well up and testing from point to point may have to be resorted to. But the water analysis is an important link in the chain of evidence.

Water analyses should be tabulated in some convenient form for ready comparison. In this connection one is struck by the interesting method of the interpretation of water analyses elaborated by Chase Palmer, and described by him in U.S. Geol. Survey Bulletin 429, entitled "The geochemical interpretation of water analyses."

Cements.—The use of cement requires careful supervision and testing. The initial setting point, and the period during which the actual hardening takes place are the two important factors to consider. These can be initially determined by laboratory process, and indicate the character of a particular cement. The laboratory test character of a cement may diverge considerably in actual use for a variety of reasons, some physical, some chemical and others mechanical.

Investigation is required on the following points:—

(1) *Quantity of Water for Mixing.*—The quantity of water used for mixing a cement is in excess of that necessary just to effect hydration, in order to preserve the necessary fluidity. This excess delays the hardening point and extends the time of final hardening. Forty per cent. is the usual percentage of water in mixing a grout for well cementation purposes. Good and intimate mixing of the grout before application is necessary. Pumping the grout under pressure will permit a thicker grout to be used.

The following table shows the results of some tests in the Baku field on the effect of excess water on the setting and hardening periods :—

Percentage of water ..	28%	30%	35%	40%	50%	60%	70%	80%
Setting .. Begins ..	6·20	5·40	6·50	8·00	8·30	10·30	11·40	12·50
in air .. Ends ..	11·20	10·40	11·50	12·00	15·00	18·00	27·50	48·00
Setting .. Begins ..	5·35	6·25	6·40	6·55	8·15	10·30	10·00	11·55
in well .. Ends ..	9·30	9·45	11·25	12·15	16·10	19·10	23·00	31·10
water —								

Times are in hours and minutes.

N.B.—With 70 per cent. and 80 per cent. of water the mass had little strength.

Strength of a Cement.—The strength of a cement increases as hardening proceeds. Thus a Portland cement made by the Santa Cruz Portland Cement Co. of California gave the following results :—

Time of hardening.	Tensile strength in lb. per sq. in. 21% water.	23% water.
Neat—		
24 hours	450 to 520 ..	400 to 440
7 days	950 to 1150 ..	850 to 950
28 „	1020 to 1200 ..	950 to 1000
Mixed with 3 parts sand—		
7 days	320 to 360 ..	340 to 370
28 „	400 to 750 ..	420 to 480

Effect of passing through well water.—However carefully a grout may be carried to the point of application, it must somewhere come into contact with the waters of the well, and these may have a deleterious effect upon the setting and hardening qualities of a cement. Previous experimental tests with the well water may give important information in this respect.

This question was carefully investigated some years ago by a special commission in Baku, and the results are of some interest, and are given in the following table :—

Table I.

Kind of water ..	Fresh.		Sea.		Well.	
Setting point ..	Begins	Ends	Begins	Ends	Begins	Ends
Test with 28% water..	2·10	6·20	3·10	7·25	4·50	8·20
Test with 50% water..	7·50	21	9·17	17	8	15

Times are in hours and minutes.

This table shows that sea water and these particular well water delay the beginning and end of initial setting periods.

Kind of cement to be used.—In oilfield cementation a quickly hardening cement is desirable, as reducing the time during which the grout may possibly be in contact with waters having a deleterious effect. At the same time, the grout should not have a too rapid initial setting point, in order to enable it to be carried safely to its point of application before the commencement of hardening. This is especially requisite in the case of deep wells. A slowly initial

setting, but a rapidly hardening, cement would therefore appear to be the most suitable.

Effect of the presence of oil.—It is interesting to note that it was determined experimentally in Baku in the same tests already referred to that the presence of oil in the well water had little or no effect on the hardening quality of the cement.

Effect of motion.—The action of gas in a well, by causing agitation may prevent a cement from hardening quickly or even at all. It is possible, however, by increasing the quantity of cement, that this action may be deadened.

Effect of temperature.—An increased temperature of the water used for mixing would appear to hasten the hardening and setting of a cement grout.

The above are a few points upon which further information is very desirable in the use of cements.

A specification for cement formerly used on the Russian oilfields is attached.

III. Mechanical.

The third subdivision into which the treatment of this subject naturally falls is that of the mechanical means adopted for combating the encroach of water upon the oil strata.

The need of co-operation by the oilfield operators is as essential in this as in the more preliminary stage of collating geological or chemical information or the results of test drilling.

Careful supervision to ensure that proper and systematic casing has been carried out in accordance with the geological results and general experience of the field, is a matter of importance for the common welfare.

Diagram 2 shows some typical situations that may arise in dealing with water questions on an oilfield.

Case I. shows the simplest case, one string of casing shutting off several water sources situated above the oil series. In the Yenangyoung field, for example, this shut off takes place at about 1000 ft.

Case II. shows a particular case of the first example. One of the water sources lies nearer the oil horizon, with a sufficient intervening stratum in which to effect the shut off. The Singu field of Burmah might be cited as an example of this case.

Case III. shows the common case of an oil source lying between two water sources. An instance of the method of dealing with this problem as shown is in the Krimskaya field of Russia. The method involves the expenditure of two strings of casing in order to protect the oil source from both water sources. The oil source may have been exploited before proceeding to protect it from the lower lying water source.

I. and II.—Ordinary water shut-off above the oil sands.
III.—Protecting a dry sand by casing off.
IV.—Protecting an oil sand between two water sands, standard method.
V.—Protecting an oil sand between two water sands, casing off.
VI.—Water sand lying close above an oil sand.
VII.—Protecting a dry sand by casing off.
VIII.—Protecting a dry sand by mudding off.
IX.—Protecting two oil sands against an intermediate water by casing off.
X.—Protecting two oil sands against an intermediate water by mudding off.
XI.—Russian water shut-off.

DIAGRAM 2. DIAGRAMMATIC SECTIONS.
TYPICAL WATER SHUT-OFF SITUATIONS.

Case IV. illustrates a possible means of saving the casing of Case III. by mudding off or injecting cement in the water and oil sources.

Case V. shows the case of an oil source above a water source, and in close proximity to it. In this case ordinary casing water shut off methods, either by formation or cementation, would be difficult or impossible to apply. Mudding off the water, or cement injection, might be tried as a remedy, or the oil source abandoned as in the case of the upper oil sources in the Grosny field under these circumstances.

Case VI. shows the converse to Case V.—a water source underneath an oil source and close to it, separated by a thin impervious parting. When the relative positions of these two horizons are known, careful drilling can prevent passage into the underlying water. If passed into, however, this becomes a case of dealing with as bottom water in the oil source, by some cementation method such water as the MacDonald process. Care must be taken in these cases not to mistake such water as edge water.

Cases VII. and VIII. show means of dealing with dry sands. Case VII. shows the radical method, but one expensive in casing. Mud fluid used in the course of drilling, as shown in Case VIII., would effect saving in casing.

Cases IX. and X. show instances of a water sand lying between two oil sands. Case IX. shows the large expenditure of casing necessary for the protection of the oil sands. A successful mudding off, or cement injection into the water sand, would result in saving at least one string of pipe, as shown in Case X.

Case XI. shows the Russian method of cementation at each shoe, followed by the main cementation made between the casings. This procedure is called for on account of the use of riveted casing in those fields.

It is not proposed to go in great detail into all the water shut off methods practised, but just to describe and illustrate the salient points of the chief methods.

It is quite probable that some of the earliest attempts at water shut off were made in the Baku field, where records go so far back as 1890. All kinds of materials were tried in the early days on that field, ranging from asphalt, clay, alabaster, fine sand, and finally cement. Even in latter years successful shoe cementations were made with clay.

During the last twenty years, however, the greatest strides have been made in the U.S., and the methods there proved and tried are now in use in most oilfields.

There are two main methods :—

(1) Shutting off in the formation without the assistance of auxiliary materials.

(2) With the use of auxiliary materials, such as clay or cement.

Formation shut off.—Where the formation consists of suitable beds of clay or similar plastic material top waters may be shut off by pressing the casing into the non-underreamed part of the hole. To effect this efficiently some long form of casing shoe should be used. This method is not reliable in soft loosely held formations. The use of heavy mud fluid between the casing and the wall of the well is an additional help.

Formation shut off is largely practised in Rumania, and I am indebted to Mr. Frank Dabell for some notes on its application in that country.

Water shut off in Rumania is generally effected by setting hermetic casing into a hole of reduced diameter and in a clay stratum.

The industry is happy in finding constantly recurring beds of "huma plastica"—plastic clay—with absence of the hard nodules so often responsible for deformed casing shoes.

Moreover, the constrictive character of Pontic clays may be relied upon to assist the operator in obtaining the desired result when the casing shoe is not efficiently bedded.

A case is reported in Moreni where 330 metres of 15½ inch casing, suspended in a 21 inch hole and left for 60 days, passed the water shut off test. Liquid at the back of the column remained at floor level.

Cement is occasionally used but generally for strengthening purposes.

Rumanian Mining Laws demand that a well under test for water shut off shall have a depth of 1 metre below the casing shoe and a water level of not more than half the depth of the well, less 10 metres—the well to remain under these conditions for 24 hours and show no rise or fall in water level.

Formation shut off is also used in Burmah chiefly on the Yenangyoung field, where the top water can be quite effectually shut off by this method.

Where possible, formation shut offs are desirable in test wells in new territory, as it is usually possible to free the casing, should other water sources appear below the one shut off, and so save expense in casing.

A particular form of formation shut off is the one practised on the Grosny field, as introduced so far back as 1900 by Mr. E. K. Wallen. It is of historical interest, as indicating the principle upon which the greater part of cement shut offs take place to-day. This method was described in a paper read by Mr. Wallen before the Terski Imperial Technical Institute in 1910. The apparatus is only a form of cementing plug as used to-day. Where good clay strata are absent, or where columns do not go far, as is often the case in Russia, this method of formation shut off has given good results, and has been effective prior to carrying out the main water shut off with cement at a greater depth.

The second division of water shut off methods involves the use of cement, and has led to the introduction of the present methods of casing cementations. The so-called "shoe cementation" of the Russian field was an early attempt. It was practically the same as the tubing method of cementation with packer (Diagram 3, Case II.) of the present day.

The chief modern systems in vogue to-day for excluding top or intermediate waters by cementation, and the methods of introducing the cement to the point of application, may now be summarised.

In all such cases one of the essential requirements is first to obtain a good circulation, either with water or mud fluid, outside the casing, in order to ensure a clear space for the cement between the casing and the wall of the well. This is also aided by underreaming during the later stages of drilling.

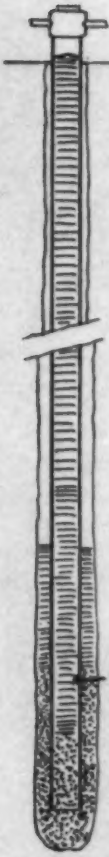
Diagram 3 illustrates in diagrammatic some of the chief water-shut off methods in use at the present time.

1. *Dump Bailer Process.*—(Case I.)—The cement is placed in the bottom of the well by means of a dump bailer after the casing has been raised off the bottom. The cement is forced up outside the casing by lowering the casing which has been filled with water and closed off at the top by means of a screw head, or by attaching some form of plug to close off the bottom of the casing.

This method is only to be used when small quantities of cement are in question. It may be used also for dealing temporarily with edge or bottom water. A particular form of this method is the one already shown as having been used in the Grosny field.

2. *Tubing method.*—(Cases II., III., IV.).—This method is used when it is necessary to employ large quantities of cement. It is fully described in the Bureau of Mines Bulletin No. 232. The cement is introduced to the bottom of the well by tubing (Case III.). The usual method of forcing the cement up outside the casing is that of filling the casing with water and closing off the top with a screw head, and then lowering the casing to its place, when the weight of casing and water forces the cement up outside the casing. Or, instead of filling the column with water, the cementing pipes are run with a special cement retaining packer (Case II.), on the principle already mentioned as used in the Russian fields. This prevents the cement from coming up the casing, and the pumps force the cement up outside.

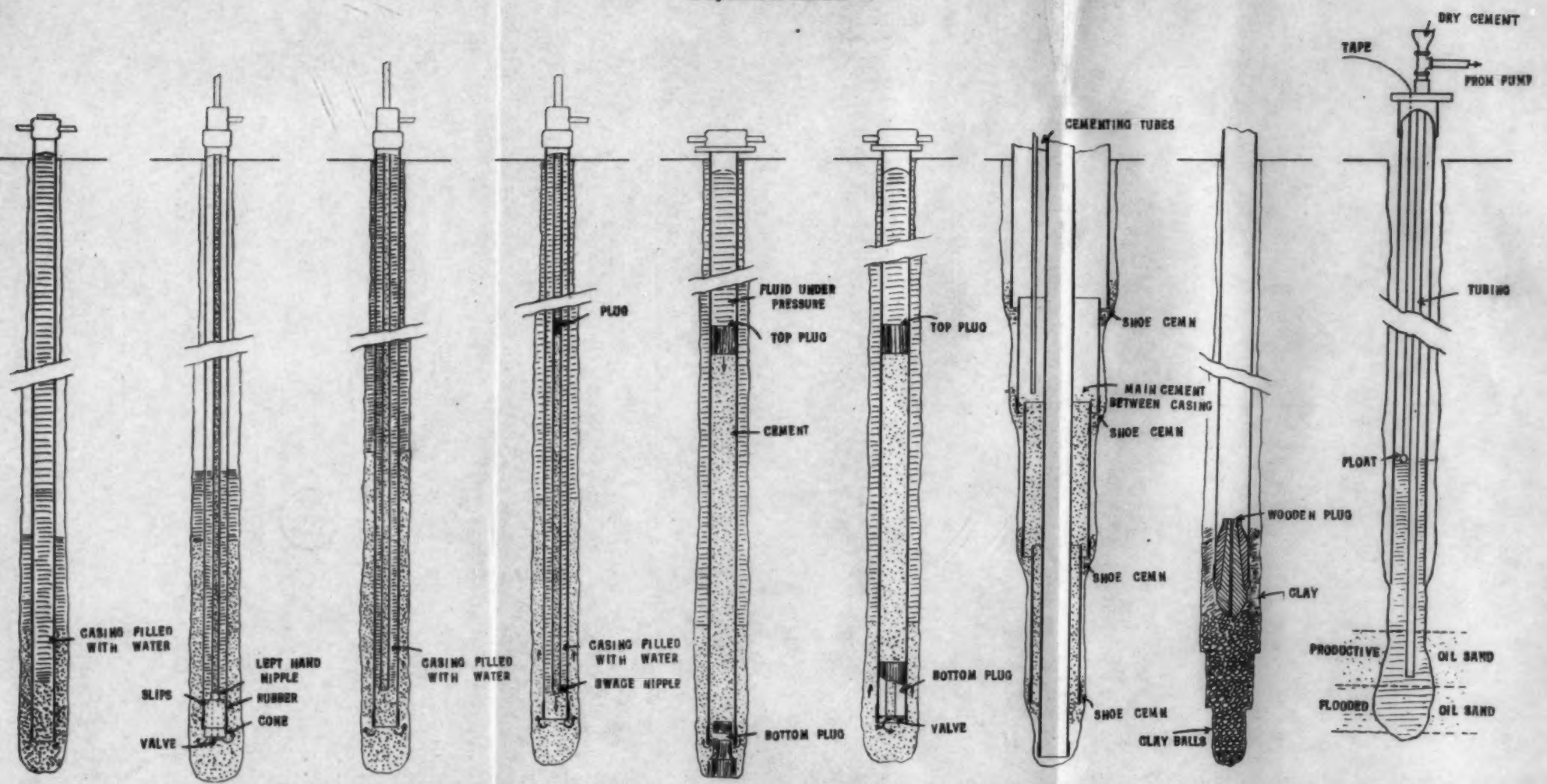
In either case, after all the cement has been introduced, a calculated quantity of water is pumped through the tubing to wash the cement out of the tubing. A regulating plug is sometimes inserted in the tubing (Case IV.).



I.
Dump Bailer meth
of cementation.

TYPICAL METHODS OF WATER SHUT-OFF.

Diagrammatic Sections.



I. mp Bailer method of cementation.

II. Tubing method with packer.

III. Tubing method [open tube].

IV. Tubing method with one plug.

V. Perkins method with bottom plug below shoe of casing.

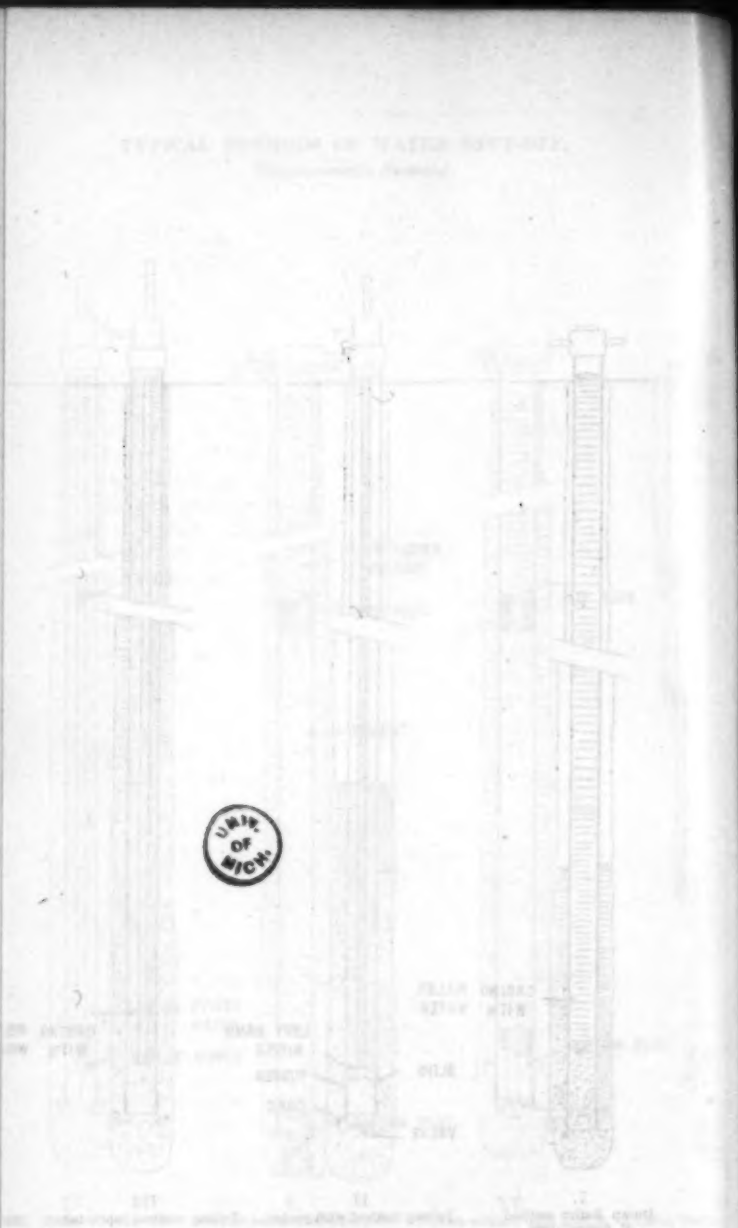
VI. Perkins method with bottom plug in casing.

VII. Russian method of cementation.

VIII. Wallen clay water shut-off.

IX. McDonald process for bottom water shut-off.

DIAGRAM 3.



The disadvantage of the tubing method over the plug method, to be described, is that of the time necessarily lost in lowering the tubing.

In a particular case taken from practice in Burmah some years ago, the procedure was as follows, and is much on the lines of the generalised method given above (Case III.). The well head was capped with a screw plug, through which passed the 2-in. cementing tubes, which rested on a lead washer to the water string screw plug, so making a water-tight joint. Flexible tubing lead from the 2-in. piping to the pump. A circulation was first obtained, the pressure during this process rising to about 200 lbs. per square inch. In order to avoid washing out the cement at the bottom of the shoe, just enough water was washed through, to clean the 2-in. pipes. The cement was mixed in two tanks to as thick a consistency as possible, but so as to flow easily through the pump and pipes. Eleven inches of water, in a 7 ft. 6 in. diameter tank, was just about sufficient to obtain the right consistency with 20 barrels of cement. The cement was carefully sifted into a large flat wooden box, and thence shovelled into the cement-mixing tanks. The grout did not require actual pumping, as it fell away by its superior weight, the pressure during passage of cement being nil. At the end, however, when pumping the clearing water the pressure rose, and this no doubt helped to force the cement up outside the casing. In this particular case 35 barrels of cement were used. The casing dropped freely into place after the cementation had been completed. The screw head was at once removed and the cementing tubes raised.

3. *Plug method.*—To obviate the disadvantage of having to use a string of piping for conveying the cement to the point of water shut off, the use of plugs or barriers was devised. The best known and most used is that known as the two plug or Perkins process (Cases V. and VI.) Exact details of this process can be studied in several of the Bureau of Mines Bulletins, e.g. Nos. 163 and 232.

As usual the first essential is to obtain a satisfactory circulation, either with water or mud fluid. The casing has to be lifted off bottom prior to this. The top plug is then inserted. The function of this plug is to act as a barrier between the water or mud fluid in the well and the cement grout. The cement is immediately pumped in on the top of the plug. After all the cement has been placed the top plug is inserted. As an additional check and safeguard the water now pumped in on the top of the second plug is carefully gauged or metered. From the quantity of cement placed a rough calculation of the quantity of water necessary to pump in behind the second plug, can be made, and this affords a check, without trusting blindly to the second plug reaching the

first. If all goes well when this happens the pumps will show a sudden rise in pressure or will stop. On this occurring the casing is lowered to the bottom and the well allowed to stand the requisite time for the cement to harden.

The advantage of this method is that large quantities of cement may be used, and put in quickly and efficiently, it is simple, and may be used for both cable and rotary wells.

The patented Halliburton method is a modification of the above in that a tape and plumb bob measure the passage of the second plug. Other modifications of this method are the use of one plug, dispensing with the bottom one, or dispensing with both plugs. In the latter case the water used behind the cement must be very carefully measured. There are other modifications which need not be described here.

Case VII. shows the usual Russian cementation method. Each string is cemented at the shoe and the casing cut as shown. The final cementation is made between the outside and inside and outside strings.

Case VIII. shows a particular form of cementation practised on the Grosny field, using clay as the material for the shut off. It was devised by Mr. E. K. Wallen so far back as 1900, and has been largely used with successful results on the field mentioned. The method was described in a paper read by Mr. Wallen before the Terak Imperial Technical Institute in 1910. The diagram shows the wooden plug used by Mr. Wallen for closing off the bottom of the string of casing, which is then lowered on the top of balls of clay previously placed in the well by means of a special type of dump baler.

Case IX. shows the MacDonald system of cementation. This depends upon a principle of introducing the cement, different to that previously described. It is used for dealing with bottom water, more especially on the Illinois field. A certain head of water in the well is requisite. Neat cement is passed into the tubing through which water is being pumped. The bottom of the tubing is lowered to near the watered portion of the sand. The latter becomes gradually plugged with the particles of cement, the progress of the plugging up being measured by the rise of the water column in the casing, as indicated by the rise of the float.

In the American fields cementation of wells is largely done by contract. Portable cementing outfits for the Perkins and Halliburton processes are commonly used. Each outfit of this kind consists of a motor truck mounting two pumps, low pressure $10\times4\frac{1}{4}\times10$, and high pressure $10\times3\frac{1}{2}\times10$, and the necessary iron mixing boxes. Otherwise the mud flush pumps of a rotary drilled well can be used.

In new fields where the well has already penetrated into underlying oil sands, the same methods described above may be used, relying upon the principle that fresh oil sands will not absorb a large amount of water or mud-laden fluid.

Mud fluid.—Some mention ought to be made of the use of mud-laden fluid in dealing with water-bearing sands. By this method many sands (not only water, but gas also), through which it is desired to drill, can be sealed off, and so conditions reimposed that were prevalent under natural conditions before the drill had pierced these sands. What, for example, was done in the Baku and Grosny fields by means of the clay shut off already described, could probably have been effected as efficiently by forcing a heavy mud-laden fluid into these sands in the course of ordinary drilling. The mud also protects the casing from corrosion. The mud-laden fluid by closing off unwanted gas sands assists in preserving quietude in a well where agitation due to gas would affect the final cementation.

In all the cementation methods in use at the present day the chief principles to observe are :—

(1) the thorough preparation of the well to receive the cement. In this good circulation is the important consideration.

(2) the use of a good quality of cement, mixed with just sufficient water to give the necessary fluidity. The usual practical proportion is 40 per cent. of water.

In the methods described the maintenance of a water shut off depends upon the stability of the casing, which is the foundation upon which such cementations are built. The question has been raised whether the injection of the grout under high pressure into the sands themselves may not effect a direct water shut off independent of casing, and for all time. We see this method exemplified in some way by mud-laden fluid shutting off water, if only temporarily. In a recent interesting investigation by Mr. A. Knapp (Am. Inst. Min. & Met., Feb., 1923), he showed that the penetration of cement into sands was less than mud. Also that a mixture of mud with cement, the latter even in small proportion, made a good wall-supporting material. Cementations into the sands under pressure, if practicable, would result in much saving of casing. This method has been used to some extent for shutting off bottom waters, edge waters, or waters in the bottom of an oil stratum. If the permanence of injecting mud-laden fluid under pressure is assured this would also meet the case. Some further research in these methods is desirable.

After completion of the water shut off and the lapse of time required for the cement to set, the shut off has to be tested for effectiveness. This applies also to formation shut offs. The

liquid is bailed out, or lowered, and after a 24 hours' standing, is tested for any rise in level. Frequently this test takes a double form, the first before the well is cleaned below the shoe, in order to test the casing for soundness, and the second after the well has been cleaned some way below the shoe, in order to test the efficiency of the water shut off itself.

TABLE II.

COLLAPSING PRESSURES AND CAPACITIES PER LINEAR FOOT OF LAP-WELDED CASING OF SIZES COMMONLY USED IN CALIFORNIA.

Size. in.	Weight per ft. lb.	Outside diameter. in.	Inside diameter. in.	Thickness. in.	Collapsing pressure per sq. in. lb.	Equivalent water column. ft.	Water column with safety factor of 2. ft.	Capacity per linear foot. U.S. galls.*	Capacity per linear foot. Cubic ft.
4½	16	4·75	4·082	0·334	4,710	10,850	5,425	0·6792	0·0908
4½	12·85	5·00	4·506	0·247	2,900	6,680	3,340	0·8281	0·1107
4½	15	5·00	4·424	0·288	3,610	8,320	4,160	0·7982	0·1067
5½	20	6·00	5·352	0·324	3,290	7,580	3,790	1·1677	0·1561
6½	20	6·625	6·049	0·288	2,380	5,480	2,740	1·4916	0·1994
6½	24	6·625	5·921	0·352	3,220	7,420	3,710	1·4295	0·1911
6½	26	6·625	5·855	0·385	3,650	8,410	4,205	1·3974	0·1868
6½	28	6·625	5·791	0·417	4,070	9,380	4,690	1·3667	0·1827
6½	20	7·00	6·456	0·272	1,980	4,560	2,280	1·6988	0·2271
6½	26	7·00	6·276	0·362	3,100	7,140	3,570	1,6061	0·2147
6½	28	7·00	6·214	0·393	3,480	8,020	4,010	1·5739	0·2104
6½	30	7·00	6·154	0·423	3,850	8,870	4,435	1·5440	0·2064
7½	26	8·00	7·386	0·307	1,940	4,470	2,235	2·2240	0·2973
8½	28	8·625	8·017	0·304	1,670	3,850	1,925	2·6204	0·3503
8½	32	8·625	7·921	0·352	2,150	4,950	2,475	2·5583	0·3420
8½	36	8·625	7·825	0·400	2,630	6,060	3,030	2·4962	0·3337
8½	38	8·625	7·775	0·425	2,880	6,640	3,320	2·4648	0·3295
8½	43	8·625	7·651	0·487	3,510	8,090	4,045	2·3863	0·3190
9½	33	10·00	9·384	0·308	1,280	2,950	1,475	3·5899	0·4799
10	40	10·75	10·054	0·348	1,420	3,270	1,635	4·1210	0·5509
10	45	10·75	9·960	0·395	1,800	4,150	2,075	4·0440	0·5406
10	48	10·75	9·902	0·424	2,030	4,680	2,340	3·9976	0·5344
10	54	10·75	9·784	0·483	2,510	5,780	2,890	3·9026	0·5217
11	47	11·75	11·000	0·375	1,380	3,180	1,590	4·9334	0·6596
11	60	11·75	10·772	0·489	2,220	5,120	2,560	4·7307	0·6324
11½	40	12·00	11·384	0·308	840	1,940	970	5·2827	0·7062
12½	40	13·00	12·438	0·281	500	1,150	575	6·3083	0·8433
12½	45	13·00	12·360	0·320	750	1,730	865	6·2298	0·8328
12½	50	13·00	12·282	0·359	1,010	2,330	1,165	6·1497	0·8221
12½	54	13·00	12·220	0·390	1,210	2,790	1,395	6·0869	0·8137
13½	50	14·00	13·344	0·328	640	1,470	735	7·2598	0·9705
15½	70	16·00	15·198	0·401	790	1,820	910	9·4150	1·2586

* Figures in this column determined by multiplying corresponding values in cubic feet by 7·4805.

In all matters appertaining to water shut off as practised at the present, the importance of casing is evident. Mention has been

made of the desirability of being able to effect direct water shut off in the water sands without the intervention of casing, but at the present time this is probably not a practical proposition. In order to carry a string of casing to great depth, with an ever increasing water pressure, casing must be of strong scantling. It is evident that the resistance to outside collapsing pressure is of more importance than that of internal pressure. One questions whether casing should not be subject to external pressure tests before leaving the works.

Tables based on Stewart's formula for calculating the collapsing pressure of different sized casings have been prepared (Table II.). In these the limiting length of water column with a factor of safety of 2 are given. Engineers will realise that this factor of safety is almost perilously low, and therefore the column lengths given in that table should not be exceeded. In shutting off several water sources it will be found cheaper to carry one string of heavy scantling than making two shut offs, as might have to be done with lighter casing.

Some interesting data were recently published of deep well cementations in California. These have been tabulated below:—

Locality, etc.	Depth of Cementation. ft.	Diam. of Well. in.	Wt. of Casing in lbs.	Cementation. No.	Cementation. Qty. in tons.	Result.	Remarks.
Union Oil Co. Rosencrantz Well No. 1.	3916	8¼	36	1	20	Fail	
				2	5	Fail	
				3	5	Fail	
				4	4	Fail	
	3936	6¼	26	5	4	Fail	Deepened 20 ft.
				6	3	Fail	
				7	3	Fail	
				8	3	Fail	
				9	3	Fail	
				10	5	Fail	
	3958	4¼		11	3	Fail	Deepened 22 ft.
				12	1	Fail	
	4013	6¼	26	13	5	Fail	4¼ in. and 6¼ removed.
				14	1		Cementation successful and well brought in with 600 barrels.
Union Oil Co. Howard Park No. 1.	4038	8¼	36	1	20	Fail	
				2	5		Successful, and flowing well.
Superior Oil Co., Long Beach	5280	8¼	36		10		Cemented through perforation at 3478 ft.

Difficulties of cementing must increase with depth, as the setting of the cement has to be considered. It is said, however, that in

California, in dealing with these wells about 25 tons can be pumped in in 45 minutes.

Conclusion.

The record of dealing with water troubles in oilfields shows steady progress during the last twenty years in all the technical branches involved. The recognition that this is a matter for common and concerted action by all workers and interests on an oilfield has been mentioned and should be stressed. On the mechanical side a few well tried methods have been evolved and are now in general use. Increased knowledge of the underground conditions prevailing in the matter of structure, character of sands, and the behaviour of liquids in these sands, have helped towards solving many problems. The interest of manufacturers in supplying materials like cement and casing to suit the requisite conditions is also a matter of note.

The author would like to express his thanks to Mr. Frank Dabell for his notes regarding Rumanian practice, to Mr. E. K. Walker for permission to use his diagrams published with his paper to the Terek section of the Imperial Russian Technical Society, and to Mr. Ashley Carter for the loan of two slides.

APPENDIX.

Specification for Cement.

The whole of the cement is to be highly-burnt pure Portland cement of the best quality, free from lime, slag, dust or other foreign material mixed with it after the cement has left the kiln. The cement, neat, must not set in less than one hour. It is to be ground so fine that the residue on a sieve of 5800 meshes to the square inch (equal to about 76 per lineal inch) shall not exceed 10 per cent. of the whole by weight.

Strength and fineness.—The cement, when tested neat, is to be mixed with about 17 to 20 per cent. of water, and shall then be capable of sustaining a tensile strain of 400 lbs. per square inch seven days after being made into briquettes, during the last six days of which the briquettes have been immersed in water. At the expiration of 28 days the briquettes shall be capable of bearing a tensile strain of 550 lbs. per square inch, having been immersed in water during the last 27 days.

Test with sand.—The cement, when tested with sand, is to be gauged with three times its weight of dry sand, which has passed through a sieve of 400, and been retained upon one of 900 meshes to the square inch. The cement and sand having been well mixed dry, about 10 per cent. of their weight of water is to be added,

and briquettes formed in moulds of one inch sectional area at the weakest parts. The briquettes, having in the meantime been kept in a damp atmosphere, are to be put into water 24 hours after they have been made, and shall remain in water 27 days more, when their tensile strength is to be tested by the architect or engineer and must bear, without breaking, a weight of 200 lbs. per square inch.

The strain to be applied in all cases at the rate of 200 lbs. per minute.

Chemical tests.—Besides these mechanical tests, the cement will be tested as to its chemical character, and as to its specific gravity, which is not to be less than 3·10, and if not found satisfactory in every respect, will be rejected.

Appendix 2.

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DISCUSSION.

The President thought the paper was one of very great practical value and had no doubt the members would wish to convey to the author the thanks of the Institution for the trouble he had taken in preparing it. The danger of water in an oilfield brought together in a very close practical association two out of the three of the constituent types of petroleum technologists, while the chemists came in sometimes as accessories. Oil exploitation differed essentially from ordinary mining, because it was impossible to make a physical examination below ground of the effects of disturbing, by drilling, the established equilibrium of subterranean fluids. It was necessary to draw conclusions from very few facts, and the imagination of the geologist must thus be kept active and mobile, ready to change with every new fact obtained by the driller. It was important to remember that the geologist's first view of the subterranean distribution of oil and water was rarely correct or even near correct, whilst it was far too late for him to revise his views after damage had been done to the field. Among the duties of a geologist there were none, he thought, in which he was so heavily responsible to his Company for faithful service as in regard to the question of dealing with water. His responsibility was far more than local. Danger by water to his Company's property meant danger at any rate to a large area of the field and possibly very often to the whole of it. It was one of those instances in which faithful adherence to established principles constituted what was best in professionalism, for it was certainly conceivable that in the immediate interests of a Company it might sometimes be more profitable to push hurriedly through a known water-bearing horizon in order to reach as soon as possible a richer oil-bearing horizon below. It was just there that the professional man should stiffen his back and insist on regard being paid to the greater public interests. The public interests did not end with the "get rich quick" stage. Far more temptation occurred when a Company had to abandon wells in, say, one locality, or altogether in its own block—wells that might not themselves pay, although situated in an area that might be paying to other Companies. But conscientious plugging of abandoned wells meant expenditure without recovery or compensation, and no conscience could be

expected of any Company to resist the temptation to get out as cheaply as possible. Nothing but rigid regulations would ever fully protect the public interests. There was nothing more irksome and nothing more dangerous than State regulations based on imperfect knowledge. Regulations of that sort might be as useless very often as they were protective. Nothing but good therefore could follow from discussion of the subject of the paper. The subject was never finished, for every field was a law unto itself, and the more the Institution obtained in the way of illustrative examples, the more the members would approach the establishment of principles fit for practical application. The larger companies with wide interests in a field and a long future before them to safeguard were as keen on protective measures as any State Government. But conditions for the granting of licences and leases necessarily must permit of the incursion of smaller companies; and the smaller companies had the power to do many thousands of pounds worth of damage for every pound worth of oil that they might be able to extract. Naturally every company looked with real suspicion on new restrictive legislation, and he thought rightly so; for whilst restriction was necessary in the public interest, restrictive interference was always expensive to some degree to the Company. But in dealing with water dangers, companies with a real continued interest in the field might justifiably admit of a greater amount of interference. They might permit of the curiosity, even the the impertinent curiosity, shown by properly qualified State officials in order that the essential local facts might be obtained. He stressed that particularly, because the facts that were required to build up the principles for the formulation of regulations suitable for local application must always be a local problem. Most countries were so backward in that respect that it was difficult to exaggerate the importance of studying the question which the author had brought forward. They were now relatively indifferent to the question. He said "'relatively indifferent," and he was sure those who had any connection with coal mining would agree with him that that expression was fairly chosen, because of the almost complete ignorance that existed of the amount of losses due to oil left behind in the ground. The losses in coal mining were known because the coal seams could be seen, and consequently they were aware of the efforts that were being made to exploit the country's coal resources more carefully than had been done in the past. But the losses in regard to oil left behind were absolutely unknown. They were not evident to those who were responsible for the completeness and thoroughness of oil exploitation. There was consequently in that matter a greater amount of indifference than ought to be tolerated.

So far as he could recollect, no paper had been read before the Institution dealing with water regulations in the different countries of the world. It seemed to him that that subject was one which a member of the Institution might quite suitably take up for special study. The members were accustomed to papers dealing with petroleum laws and mining laws in the various mining countries in the world, but he thought a far more satisfactory discussion of the question would be obtained if their study of comparative international mining law were limited to some special technical aspect of, say, oil exploitation. He offered the suggestion for what it was worth to any member who had had occasion to deal with water troubles. He spoke with recollection of the difficulties which were experienced in Burmah some sixteen years ago when an attempt was made to frame regulations, on imperfect information, for the guidance and control of those who knew more about oil exploitation than those who represented the Government. Subsequent experience in that area must have put those regulations to a very severe test, and he would be more surprised than anybody if he did not learn that those regulations now deserved very serious, even drastic, revision. He had no doubt the author would welcome a discussion on the general question which formed the introduction of his paper and of its first two or three sections, as well as a discussion of the mechanical methods which were treated so clearly and in greater detail in the main body of the paper.

The Secretary read the following statement by Mr. A. R. Neelands, of the François Cementation Company:—

I have read with great interest and appreciation Mr. Rappoport's paper on "Water Shut-Off," and my interest is in no wise confined to those technical points which touch on our own practice. On the main body of the paper we have no comments to make, as we have had no experience whatever in the drilling or casing of oil wells or the application of cementation to the problem of water shut-off in oil wells.

As our own work has been practically confined to this country, we have had no opportunity to apply the François process of cementation to this problem, but we have had considerable experience and practice in the application of cementation to the shutting off of water from other engineering undertakings, including borings other than oil, and there are some points which we might mention which may be of interest to your members, and some questions which we should like to have answered for a more complete understanding of Mr. Rappoport's paper.

In that part of the paper which relates to the chemical part of the problem, Mr. Rappoport mentions that 40 per cent. is the usual percentage of water in mixing the grout for well cementation

purposes. We take it that this is the percentage before mixing, and that 60 parts of cement by volume are mixed with 40 parts of water by volume to form 100 parts of grout. If this is a normal mixture we would like to know the maximum amount of cement that has been used and the considerations which have led to the adoption of 60 per cent. of cement as giving the best mixture. No doubt the injection pressure used would influence this, and we would like to know the type of pump which Mr. Rappoport had in in mind when giving this figure.

The figures quoted in the results of tests in the Baku field indicate that the tests were made with slow setting cement. They also show that the initial and final setting times increase as the percentage of water increases, which is normal. They show, also, that the initial and final setting times are appreciably reduced when well water is used, which, no doubt, is due to the character of the water.

In the foot note to these tests, however, it is stated that when a percentage of 70 to 80 per cent. of water is used, the mass has little strength. This note should be qualified, because Mr. Rappoport has not mentioned a rather essential point on the setting of cement in the presence of abnormally high percentages of water. When that cement sets under pressure we have systematically observed that, firstly, as the quantity of water mixed with the cement is increased, the setting time of that cement is extended, and, secondly, if pressure is applied on the mixture either during the setting time or before the setting starts, a certain amount of this extended setting time is neutralised, proportional to the amount of pressure used. While it cannot be said that by the application of pressure alone the normal setting time of cement, mixed with a normal percentage of water, can be obtained, pressure can be effectively used in minimising the lengthening of the original setting time due to the excess of water; while as regards the strength of the cement our experience has shown us that cement mixed with even as large a quantity of water as 300 to 400 per cent. can when setting under pressure give very satisfactory results as regards strength. We have cores of cement which have been extracted from boreholes injected which demonstrates the accuracy of this statement. We have even noted in some cases, when several conditions obtained simultaneously during the one injection, that the cement, after setting, may be harder than if the cement had simply been mixed with the normal quantity of water, not being subjected to pressure.

With regard to Table I, we can corroborate that sea water delays the beginning and end of initial setting periods. Generally, it is advantageous to employ cement with a moderately slow initial set but with a rapid final set.

With regard to the effect of motion, it is undoubtedly true that if the agitation of the cement is continued past its setting time, strength will be lost. As an offset to the agitation caused by the action of the gas, we would suggest increasing the pressure as well as increasing the percentage of the cement. In fact, we are convinced that an increase of pressure alone would be sufficient to enforce the proper setting of the cement in spite of the agitation of the gas.

With regard to the effect of temperature, we can corroborate Mr. Rappoport's observation.

With regard to Part III, Mechanical, we are not acquainted with the methods described. The only point we would raise with regard to the sealing off by cementation of the water making in the well is this: it seems that the different methods described are confined exclusively to the sealing of the cutting shoe of the casing tube or, at least, of a short length of the casing tube into the surrounding rock or strata below the feeder of water encountered, and if necessary above. The assumption seems to be that there is no possible communication between the water dealt with at that level and another feeder below the bottom of that length of casing tube. We have often had cases where water at different levels communicated by fissures, breaks or other channels with the one offered by the borehole itself, and in our own practice when we have to seal off a certain inlet of water into the borehole, we are not satisfied by exclusively sealing the casing tube in a watertight manner into the borehole, but we would extend the operation after the plugging of the casing into the bottom of the borehole to seal the water off to a certain distance from the borehole. This is done by our ordinary cementation process.

With regard to the actual sealing of a casing tube itself into the borehole, we have never found it necessary to adopt the rather elaborate methods described, or other similar methods. This may be due to the fact that our injection of the casing is made directly and under high pressure, or it may be that the problems of sealing in the case of the oil-wells is more difficult than we have met with in our own practice.

With regard to the injection of mud fluid, we can confirm the results of Mr. A. Knapp's investigation that the penetration of cement into the sand was less than the mud. In our own experiments in cementation and during the invention and perfection of the Silicatization Process, we found that cement was one of the most difficult of all substances to inject into sands. We consider, however, that in all cases where the mud fluid injection could be used successfully, that the use of our silicatization process would

be much more efficient, although, of course, the cost of the chemicals necessary might be a bar to its use.

Finally, in general consideration of Mr. Rappoport's paper, it would seem that no special consideration has been given up to the present to the possibility of casing a borehole by cementation instead of casing the same with steel casing sealed in after placing. Mr. Rappoport touches on this possibility on the conclusion of his paper, and it is in our opinion a very interesting possibility. We have adopted this method successfully in the case of short boreholes, but are not sufficiently conversant with oil wells for our opinion to be of any value in this matter. We believe, however, that the possibility is worth investigating, and in so far as our knowledge goes, we see no reason why it could not be adopted, at least where the strata conditions are favourable and where the borehole is not expected to be kept in use more than a short period.

Prof. Nash said the first point raised by the author was the statement made in the early part of the paper that rich upper sources of oil were flooded at the present time and useless for oil production, and that it was now realised that the menace did not affect individual wells only, but the oil-field at large. Personally he was a little in doubt as to whether the statement was quite correct. He agreed that it was realised by many of the bigger companies, who had the advantage of expert geological advice constantly at hand, but he had had evidence in the past that it was not always realised by some of the smaller companies He wished the author had given a section showing how an oilfield could be flooded by the adoption of casing programmes which were not uniform throughout the field. No matter how careful the bigger companies might be, the smaller companies could do just as much damage as the larger companies in that respect. Reference was made in the paper to the entrapping of oil due to the presence of bottom waters. Such a contingency in some fields was very common, especially where a sand had different degree of permeability throughout its vertical section due to its method of deposition. He had had experience of cases, in which, with rapid bailing or pumping, considerably more water had been brought into the well, and considerably less oil, whereas with more gentle pumping the water had been kept back to a great extent, the reason for this being that the oil in the upper portion of the sand body, which was less porous, could be passed by the water in the lower and coarser portion, if the well were forced. In the case of slow pumping, of course, exploitation had not gone on quite so quickly as it might have done. One method of getting over that difficulty was by cementing the waterbearing portion of the sand by the McDonald method, a very delicate operation which could be performed quite simply,

however, if proper care were taken. The next point the author raised was the importance of excluding waters from dry sands, because such sands could act as a conductor and carry water to other wells. In his opinion that was the most important statement made in the paper. The members would know of many oilfields in which the oil sands had been flooded due to that cause. The President had put forward some views that evening, which he had intended to express, regarding the danger of incomplete geological information as it affected the water problem; such ignorance being either general, as often prevails at the commencement of operations, or through lack of co-operation amongst companies with small working capital. His own experience had been that much of the trouble arose in the early days of the field, when the field had been newly discovered and before geological evidence had been obtained otherwise than from surface indications. He thought it would be a very courageous Government Department which insisted on each water being shut off as it was encountered, yet this was the only means of protecting a new field until such time as the water problems were thoroughly understood. In the earlier part of his paper the author referred to the fact that co-operation had been established amongst operators. He would like to confirm that statement so far as the bigger companies were concerned, but up to the time of his leaving the industry, three years ago, it was his experience that it had not been established amongst the smaller companies. In his opinion, when a new field was started, a central geological station should be formed by the Government, as was done in some places, which would possess autocratic powers to insist on complete and correct logs of wells being sent to them, and that this central station should have the power to insist on a casing programme for the protection of the whole of the field. In some cases that system was at present adopted. In others there was what was called a Technical Commission, which simply meant that representatives of the companies sat on this Board, and the Company with the largest number of subsidiary companies had the greatest number of representatives, the result being obvious to anyone. He would like to see the rules in that respect made more stringent than they were at the present time. If they were, much less would be heard about the flooding of oil sources. The difficulty referred to in the paper, in cases in which the bottom waters were separated from the oil by a thin stratum, could, of course, be overcome very easily by the McDonald method he had already mentioned.

Where there was an intervening stratum of clay or any material of that kind a packer might be used and much greater pressure, so that the results were more positive. He was quite in agreement

with the author's remarks in regard to the chemical analysis of water, but how many oil companies analysed their well waters?

It was true that a certain number of American companies were doing so at the present time, and it was done for years by the German companies on the Rumanian oilfields before the war. One of the surest tests of determining whether a water in a well was newly struck water or old water which had broken in from the shut-off was by a method of chemical analysis, because most underground waters contained something like twenty different metallic salts, all of which occurred in different waters in varying proportions, so that identification was not difficult. One method he had used, which was not mentioned in the paper, but which he considered would be simpler than the plugging up of the well and testing from point to point, was the use of a colour indicator behind the casing. For that purpose he had used methylene blue and methyl orange, both of which colours were fast in water. If, in the case of methyl orange, the colour went through the shoe so diluted as not to be possible to identify the colour, by the addition of alkali or acid, the colour changed to a deep yellow or a deep red respectively. In some cases in which the water contained lime or CO_2 the colours would turn of their own accord from chemical reaction due to these ingredients being present in water. He suggested that the best cement for use in wells was hydraulic cement employed by civil engineers in dock and harbour construction for underwater grout work.

A special cement was manufactured by cement companies for that purpose. The next point to which he wished to refer was the tests given to water shut-offs. An excerpt was given in the paper of a report by Mr. Frank Dabell relating to the water shut-off laws in Rumania. That method was, he thought, common right throughout the European oilfields, but he was against the test because it was not sufficiently stringent. The bailing down to half the depth of the well plus a few feet was quite good as a preliminary test for cementation, but he considered that when a shut-off was finally tested the well should be bailed dry entirely, because a time would come in the life of the well when there would be no internal pressure inside the shut-off string, and he, therefore, thought shut-off tests should be carried out under the worst possible practical conditions. A lot had been heard about the plastering of the walls of the hole with mud fluid, and he thought the time had now come when somebody with experience in that direction should state his views and bring forward facts to support them. A little time ago he tried some experiments with mud fluids of different densities under varying pressures, with different kinds of porous materials, but unfortunately they were not complete. He used a home-made

apparatus which would not stand up to the pressures that were usually found under hydrostatic conditions in oil wells, but his experiments went far enough to leave him still in doubt and still very sceptical. A short time ago, when speaking to a production engineer of many years' experience of rotary drilling on a European oilfield, he asked him if he thought that mud fluid really plastered the hole. He received the reply that he was certain it did, because the particular well which they were examining started to cave at the bottom, and all he did was to thicken his mud fluid and the trouble was overcome. He suggested that that, very possibly, might have nothing to do with the plastering effect of the fluid. All that had been done had been to increase the hydrostatic pressure due to the increase in the density of the mud fluid which the engineer was using. He certainly agreed with the author's remarks that the casing should be subjected to external pressure before leaving the works when it was borne in mind that the crushing strength of the material from which the pipe was made was lower than its tensile strength. The last point to which he wished to refer was the factor of safety, a question which had been discussed both at the Institution of Civil Engineers and the Institution of Mechanical Engineers. He thought the time had now come when it was out of date to work out stresses on the ultimate breaking strength of a material. In his opinion the elastic limi should be the basis on which calculations should be made, and no figures should be worked out on any po'nt beyond that of the point of fat'gue. When it was borne in mind that the figures for stresses given by the author were worked out on the ultimate strength, and also the fact that the pipes were tested by their internal pressure, and not their external pressure, he ventured to suggest that the pipe probably had no factor of safety at all. Many of those present had had experience, in the field, of collapsed casing and would possibly agree with him.

That brought out another point which the author raised, very opportunely, in the course of a discussion at the Wembley Congress, namely, the question whether dependence was not now being placed on the metal'urgist and the suppliers of material for deeper drilling. In his opinion this country could now obtain the drilling skill and possibly the plant, or it could have the plant very quickly with a little strengthening up and better design, to drill to depths of even 10,000 ft. or more, but production engineers were held back, not so much by the strength of the material in the drilling plant itself as the strength of the casing. He suggested that future developments with regard to deeper drilling depended on the casing supplier and not so much on the supplier of drilling plant. If the casing supplier could give a pipe which would stand pressures

at that depth, much less would be heard about the future supplies of oil becoming rapidly exhausted.

Mr. F. M. Penney said he thought it was the first paper that had been read before the Institution on water shut off, and from that point of view he had done a great service to the industry. All field men knew perfectly well that their greatest bugbear was water, either in a form which necessitated shutting off or when it occurred in the form of a quicksand which "froze" the casing and meant sometimes that the well was lost. The author had referred to defective casing as being one of the causes of the flooding of oil sources. He supposed the author had in his mind the usual troubles in the matter of defective casing, i.e., casing of faulty manufacture, or casing that had been roughly handled before being put into the well, or that had been badly strained with the blocks, or by driving when already in the well, or casing that had been subject to undue strains underground from water pressure or from moving earth pressure. There was another class of defective casing to which he would like to refer which was not so generally known but which he thought might be a more frequent cause of trouble than was generally believed to be the case, namely, casing that was rendered defective by the action of corrosive underground waters. The difficulty in that case was that the shut off might be known to be good and might last for two or three or more years. It might be known that the work was well done and that the casing was stout and good, but corrosive waters might cause trouble later on. In the Grosny field he had seen a water string of fine stout 10-in. screw casing withdrawn from a well and through the casing there were holes of 2-in. diameter made by the corrosive waters which exist in that field and which gave great trouble by attacking both the casing in the wells and the local pipe-lines that ran from the wells to the tanks. The point of interest in that matter was how the string of casing could be protected. One method of protecting the casing against corrosive waters was by injecting cement between the threatened column and a second protective column, or perhaps between the threatened column and the sides of the well. If the author knew of a better method of doing it he was sure all field men would be glad to hear it because they might meet with that sort of trouble at any time in their lives whilst they were working on oilfields.

In connection with the chemical analysis of water, Prof. Nash had referred to the staining process. Personally he thought the staining process could be very useful on occasions, because instances might occur in which two waters rather near to each other in the earth might be of similar chemical composition and then the water analysis test was of no use. If, in that case, the staining test was

used it would generally be possible to arrive at a correct conclusion. In the cases in which he had seen staining tests used a large quantity of aniline dye was put into the water which was suspected of penetrating to another well. Enough of the aniline dye powder was put in to stain a very large quantity of water with a good red tinge and, after sufficient time had been allowed for percolation and underground movement, the flooded sand or the lower water was examined to see if any traces of the red could be found. If traces of red existed there was not the slightest doubt that the water had broken through and that a connection had been established.

In connection with the mechanical shutting off of water, the author had shown on the screen some sketches of the Maikop field and he had mentioned the shutting off in a clay stratum with a long shoe as practised in Rumania and Burmah. The author would recollect that in 99 cases out of 100 that was the way the waters were shut off in drilling for the deeper oil in Maikop and with very excellent results. In those days the Commission, composed of Government officials and neighbouring oil owners, was exceedingly severe, and in practically every case the shut offs made in that simple form by driving the long shoe into the clay were successful. Another point he wished to touch upon was the Grosny method of shutting off water by a wooden plug and clay as introduced into that field by Mr. Wallen, of which the author had shown a few slides. As the author evidently had not time to go in detail into the method he thought it might be of interest if he said a few words in regard to that rather special method of shutting off water. It must be remembered that in the Grosny field a heavy adaptation of the Californian cable tool system was used. The chief difference was that the Russian under-reamer was placed permanently in the string of tools immediately above the short drilling bit, so that the whole length of the hole was reamed. When a start was made to shut off water under Mr. Wallen's method the casing was drawn back 20 to 30 ft. and balls of strong plastic clay were then dropped in by hand or deposited by the dump bailer. When the balls of clay had filled the reamed space up as far as the shoe a plug, made of ash wood, was inserted and, by an arrangement of springs and a tapered mandrel of ash wood which was inserted into it, the plug was fixed in the end of the shoe and hermetically sealed it. When the end of the shoe had thus been sealed the casing was lowered on to the clay and, by its own weight or by the aid of jacks above, the clay was pressed down and up behind the shoe and casing into the reamed space, making an excellent water shut off which had been used to a tremendous extent in the Grosny field. One or two companies had dispensed

with the wooden plug and used a water column instead. They drew up the casing and inserted the clay but instead of putting in a wooden plug they filled the casing up with water, capped the top of the casing and then lowered the casing, using the water column in much the same way that Mr. Wallen, in his system, used the wooden plug.

Mr. T. Dewhurst said he desired to confine the few remarks he wished to make to the geological section of the paper. In regard to the important subject of edge water, he wished to draw attention to an article on the subject of mining for oil which appeared in the issue of the *Oil and Gas Journal*, October 23, 1924. He was a little surprised and disappointed to find that the article in question had not been the subject of comment in the Technical Press, and in the circumstances he proposed to deal with the subject. In the first place, members would recollect that M. Paul de Chambrier, in the paper he read to the Institution, stated that at Pechelbron it was principally at the lower portion of the sand that oil could be seen oozing out slowly. That statement was confirmed in the article referred to, in which it was stated that the seepage zone at the base of the sand was generally about 20 to 25 ins. thick, and that the upper part of the sand was relatively dry. It so happened that the galleries and tunnels had been carried down the dip of the structure actually to the oil/water boundary; and in working down the slope towards this boundary it was found that the seepage of oil became more copious, and that the seepage zone, or the zone of saturation, became thicker and thicker, and finally extended throughout the whole of the tunnel face. Close to the oil/water boundary practically the whole thickness of the sand was saturated and was seeping oil. Finally the edge water was touched; this proved to be salt, and it was found to be under no very appreciable pressure and it came in very slowly when tapped by the workings. It seemed to him that that was a very important discovery. For the first time in the history of petroleum geology men had actually gone down into the oil sand and had ascertained the conditions existing at an oil/water boundary. It was interesting to note that they had found a water drive in progress, and that the evidence which had been obtained was in accordance with theoretical expectations. A further point he desired to mention was the danger of group production in relation to edge water. By group production he meant the simultaneous production of oil from two or more sands. Each sand would of course have its own oil/water boundary, and the different oil/water boundaries would occupy different positions down the dip of the structure. If the sands were being drained simultaneously in one or more wells, it followed that at a certain stage of development edge water would

come in along one of the sands, and this water might be sufficient to flood out and damage irretrievably all the oil sands which were being developed. He agreed that the really serious menace was usually overhead water, but there were possibly one or two apparent exceptions to that rule. He suggested that members who were interested might read the history of the Bradford field in Pennsylvania which was opened up in 1876. Ten years ago this was practically a dead field, as in some of the wells production had fallen almost to nothing. It was noticed, however, that in some of the wells which were producing about an eighth of a barrel per diem, the production gradually increased to half a barrel, then to one barrel and finally to two or three barrels, and it was some time before the cause of the increase was discovered. It was then ascertained that it was due to abandoned wells which had been imperfectly plugged, or had been abandoned simply by pulling out the casing. As a result surface water had entered and filled the abandoned wells, and had then entered the oil sands and had driven the oil before it into neighbouring wells. That was further proof of the importance of a water drive in the extraction of oil from sands. In that case therefore overhead water seemed to have been useful, but it was doubtless only one of the apparent exceptions which tested and proved the general rule. It should be borne in mind that in the Bradford field the quantity of oil in the sands was small, and the quantity of water was also small. There was no doubt in all ordinary cases where there was a great deal of oil in the sands, and also great quantities of overhead water, that the water was a very serious menace to the development of the sands below. There was one final point to which he wished to refer. It seemed to him that in connection with shutting off overhead water one of the most important points, and one which was usually disregarded, was that all the wells should be cemented in the impervious cover rock above the oil sand. If wells were cemented at different levels, and particularly if there were considerable differences in the levels at which they were cemented, then unless a great deal of cement was used in the deeper cementations, the water from the higher water sands might percolate down behind the water string and then migrate horizontally along one or more porous beds, and finally enter other wells below the levels at which they had been cemented.

Mr. Charles Dabell said the remarks made by a previous speaker with regard to the Bradford field eventually coming back into production reminded him of some parts of the old Grosny field, which, when he left it in rather a hurry a few years ago, had been given up owing to flooding with water. The production to a certain extent returned owing to the fact of the water travelling down the

dip of the oil horizons until it was forcing the oil back up the dip to the old wells. Wells which had been given up were at that time giving 18 to 20 barrels a day, with encouraging signs of further increase. Bearing in mind certain remarks that had been made at the meeting regarding the collaboration that was necessary between companies on the field for the protection of oil horizons from water, he was reminded that in Grosny in the old days, and probably Baku, Rumania and a good many other fields, there were times when any company or individual who attempted to gain information in detail from another company regarding the depths of the water, gas or oil horizons was looked upon with extreme suspicion, and not the slightest information was given. As a result the old field in Grosny and the old fields in other countries had been flooded owing to the lack of assistance being given by one company to another. That state of affairs to a certain extent still continued, and he thought the larger companies were the biggest offenders. They were absolutely independent; they neither asked for information nor would they give it. Probably the same thing applied to most parts of the world; he believed it to be very pronounced in Venezuela.

Mr. Harold Dabell thought an experience of his in Egypt might prove of interest.

Some time ago he was called upon, as Inspector of the Department of Mines of the Egyptian Government, to deal with a water well at Kharga Oasis. The well was a recently drilled one, its object being to obtain sufficient water for the cultivators of that oasis. In the oasis, however, are many ancient dug wells varying from 300 to 700 ft. deep, dating back to the Roman occupation. The source of the water is the Nubian Sandstone, and unlimited artesian water supply has been obtained from this source and is still being obtained to-day.

The well which required attention was 400 ft. deep with 8-in. casing to about 300 ft. From that point onward was an open hole of about 5-in. diameter. The formation is recorded as sanded clays and clays to 250 ft. and Nubian Sandstone 350 to 400 ft., approximately. It had been drilled by a native with a hand drilling plant, and was capped with an 8-in. gate valve. The water from the Nubian Sandstone had a static head of 23 ft. about ground level. With the valve closed the water was coming away from around the casing and also from cracks in the ground extending to a radius of 25 ft. from the well. Approximately three tons an hour was coming away in this manner. When open, the well would flow at full bore.

After studying conditions, he obtained a supply of Flourescene, a small petrol motor and pump with a 2-in. discharge. Pipe con-

nections were made between the pump and the well and 400 gallons of coloured water pumped in against a pressure of about 25 lbs. Very shortly this coloured water was returning through the fissures. The pump was then changed over to a thin mud fluid, and he had the idea that by first proving circulation from the well-head to surface he could, with a gradually increased thickening of the mud fluid, apply each day a coat of "paint" to the fissures, which coats would render the walls impervious, and succeeding coats over such until the fissures were entirely useless as aqueducts. In an hour the thin mud fluid was showing at the surface via the fissures and pumping proceeded all day, work being suspended at night. On the following morning, prior to recommencing of pumping, the flow from around the casing and from the fissures was markedly lessened, but still in evidence. For that day and the succeeding day liquid clay was pumped against a gradually increasing pressure, until at 135/150 lbs. liquid clay of the maximum consistency pumped was coming away via the fissures.

Upon removal of the flange at the well-head it was found that the column of liquid clay in the well was slowing dropping in level at the rate of about half an inch a minute. After falling a few feet it would begin to rise again, and the flow from the fissures ceased meanwhile. At this point eight sacks of neat cement was mixed with the balance of liquid clay in the tank and such mixture was pumped into the well at 150 lbs. pressure. Next morning the flow of water from all points, including the well, had ceased, the liquid level in the latter now being about 30 ft. from the surface. Thick mud was poured in by buckets and the well filled. This level never fell away again. The tubes were extracted slowly and the bore was kept full of mud by occasional bucketing to compensate for displacement. In all about 35 tons of mud fluid were pumped in. To-day, ten months later, the well is still dead and promises to remain so.

The lesson I have endeavoured to learn from this work and its results is that it was possible to "paint" the wells and the fissures and render them waterproof, but it was impossible to do the same to the fissures to their execution as aqueducts. The cessation of flow was attained by the settling back of the clay and cement, and the fissures thereby becoming blocked when pumping ceased. Admittedly the operations were on a small scale, but the conditions were novel and interesting.

The consequences of allowing an enormous artesian supply to have become laid bare to surface by a multiplicity of fissures and an inevitable cavity in the ground, would certainly have robbed 3000 people and 30,000 date palms of water. The Kharga Oasis, existing since time immemorial, would have had a lack of water at surface and no more artesian supply.

The Secretary read the following letter from Mr. Albert Millar:—

Mr. Rappoport in his very interesting paper has cited the Boryslaw-Tustanowice field as an example of rapid flooding. There are two explanations which account for the rapid watering of large areas of the field in question. Firstly, the fissured and faulty nature of the Boryslaw oil sand which offers little resistance to the invading water. Secondly, as the gas had greatly diminished, both as regards quantity and pressure some time before the influx of water was noticed, many wells were intensively swabbed as a means to increase production. Results proved without doubt that the suction action of the swab had greatly accelerated the watering of the oil sands.

The Mining Office adopted the disastrous policy of forcing operators to swab continuously all wells showing water, hoping thereby to exhaust the water; this only hastened the complete flooding of the affected areas, and trapped in the sand oil which might otherwise have been recovered. This intensive and continued swabbing also caused violent agitation of the oil, water, and the gas in the sand, and resulted in an emulsion being produced which defied ordinary breaking down processes.

With few exceptions, wells in the watered area were abandoned after the big fire in 1915. It is interesting to note that when several of these wells were opened up in 1923 some of them produced considerable quantities of oil practically free from water although they produced only emulsion in 1914–15.

The shutting off of bottom water probably presents the fewest difficulties. There are several methods for "plugging-back": one can use a form of concrete which is mixed on the surface and lowered to the bottom of the borehole in thin sheet iron canisters, which are broken up with the tools and tamped home; or wire rope can be cut into lengths and unravelled and tamped in with intermediate layers of cement. This results in a ferro-concrete plug. Where delay must be avoided in shutting off bottom water and cement is not available, good plastic clay dumped at the bottom of the borehole, into which a wooden plug is driven and more clay dumped on the top, will often effectually shut off the water.

When only a few feet have been drilled into the water-logged sand, lead wool thoroughly tamped into the bottom of the hole is a quick and certain remedy. This method is widely used in the United States as it is much safer and more reliable than cement, especially when the drillers are not used to handling cement. A leaky cement bottom hole plug can often be remedied by tamping in lead wool on the top.

The most frequent cause of failure in cementing wells is lack of experience in mixing the cement and conveying it to that part of

the borehole where it is required, as success depends to a very great extent on the speed with which this operation is carried out.

Cementation of wells, like the shooting of wells, has become a specialised branch of the industry in the U.S.A.; as soon as a well has been prepared, the cementing contractor brings along the necessary specially designed plant mounted on motor trucks and takes charge of the well until the operation is completed. A competent crew will handle from 20 to 35 tons of cement at an average rate of from 2½ to 3 minutes per ton. Cement is more easily handled if furnished in 100 lbs. bags than in casks.

The advantages of using mud fluid when cementing are: Firstly, it prevents caving; secondly, it scours the walls of the casing of oil or paraffin wax; thirdly, if heavy enough it will prevent agitation of the cement by gas. Another point which should not be overlooked is, that by using mud-laden fluid instead of water, the column of mud and cement behind the casing and that in the casing can be more nearly balanced, as the specific gravity of oil-field mud is from 1·4 to 1·6, and cement about twice that figure.

The setting of the cement does not appear to be adversely affected by coming into contact with mud-laden fluid, and tests carried out in the U.S.A. have proved that mixtures of mud and cement in the proportions of 20–80, 30–70, and 40–60 set quite hard, although the time taken is longer.

Mud-laden Fluid Methods have many advantages over cement in that experts are not required to make the job a success. It is cheaper, easy to handle and control and the necessary clay or mud is generally obtainable near every field; in fact, nearly all dump holes (slush pits) furnish a certain quantity of suitable mud.

Whereas cement when set is rigid, and consequently liable to be affected by subterranean movements or vibration caused by further drilling operations, clay and mud-laden fluid will adapt itself to any movement or vibrations, and the longer it stands the more effectual the seal.

If a water "shut off" proves a failure with cement it is a serious matter, especially if from 15 to 30 tons of cement or more has been forced up behind the casing. When using mud, however, the casing can be lifted and circulation again obtained in a comparatively short space of time. With the use of mud fluid, casing seldom becomes frozen and a string set with mud fluid behind it can be moved years later. It also has an advantage over "packers" which seldom take a good hold on the uneven wall surface of the bore hole, and even if a seal has been obtained, it is generally only a temporary one. Complicated shut offs where more than one water sand has to be isolated, can be effected with one string of casing when using mud-laden fluid, or a series of water, oil, gas and

dry sands can be effectually sealed and isolated one from the other by one column of mud fluid.

The consistency of the mud fluid to be used will depend upon the nature of the formations which have to be mudded off—if the sands are close grained and the shapes compact, then a thin mud fluid can be used. If the sands are very porous and the shale beds loose, a thicker mud can be advantageously employed. The consistency of the mud fluid depends upon the depth to which penetration of the sand by the fluid is desired. When it is not only a matter of shutting off water, but also of controlling gas eruptions, the mud must be of suitable specific gravity: this cannot be gauged from the thickness of the mud, as some muds which are quite thin have a higher specific gravity than others which can barely be handled by the pumps; it is therefore essential that the specific gravity of a mud should not be guessed at but obtained by weighing gallon samples.

The specific gravity of a light mud can be raised by the addition of iron oxide, containing from 70 per cent. to 80 per cent. of iron, and has the advantage of not thickening the mud to any appreciable extent. An average oilfield mud of 14 lbs. per gallon can be raised to 18 to 19 lbs. per gallon by the addition of iron oxide (Fe_2O_3).

Ordinary building lime makes a very good thickening material for mud and does not harden, whilst in some cases sawdust and finely chopped hemp rope can be used with advantage.

The selection of the right spot at which the casing should be set is of the utmost importance, and I agree with the author that longer casing shoes should be used. In my opinion they should be about 4 to 5 ft. long when cementing and about 10 ft. long when setting into a clay bed, as in Galicia and Rumania, etc. When setting a casing shoe in limestone or sand, it should not only rest on a ledge, but the borehole should be reduced in diameter so that the shoe touches and fits, more or less tightly, the walls of the borehole.

When, as sometimes happens, a string of casing has to be landed for shutting off water, and ideal conditions, such as a bed of impervious clay or a hard shell several feet thick, do not exist, the last ten feet of the hole should be drilled "tight" and filled from ten to twenty feet with a plastic clay in the consistency of putty and, after a thick mud fluid has been circulated, the casing should be lowered to its seat.

During this operation, the clay will not only be forced up behind the shoe, but into any irregularities and cavities in the walls of the borehole. From practice I have found this to be a most effective method where a string of casing has had to be landed in shale beds directly overlaying the oil sands, in fact clay can be used with advantage in every case where a shut off with mud-laden fluid

is being made. Where a shut off is made with mud-laden fluid, the wells should be allowed to stand for three days to allow the mud to settle.

Casing.—The factor of safety of 2 is, as the author says, perilously low, in fact it is dangerous, and it is difficult to understand, when from £10,000 to £30,000 is spent on equipping and drilling an oil well, why such a long chance is taken at the very last stage of the work. A factor of safety of 3 should be the lowest permissible, all casing should be weldless because, in the manufacture of weldless steel casing, higher tensile steel is used giving greater strength for the same weight and thickness as compared with the lower grade used in welded pipe. The factor of safety of 2 is worked out on the assumption that casing is perfectly round. Quite recently I was examining numbers of strings of various dimensions casing, and found very little that was quite round, in fact there were variations of from a 32nd in. to 3/16ths in., ¼th in. being quite common; this greatly reduces the resistance to collapsing and would lessen the safety factor of 2. Wherever possible casing should be used in lengths of not less than thirty feet, and for all sizes under 12 in. ten threads per inch should supersede the 8 thread joint.

I consider the inefficient plugging of wild-cat and non-productive boreholes a source of great danger. Taking as an instance several wild-cat wells being drilled on what to all intents and purposes is a likely structure; the boring may only have resulted in small oil and gas shows, in most cases the casing is pulled out and practically no plugging is done so that the water has unhampered ingress to any sands drilled through. Sooner or later, somebody more fortunate in their selection of a location may open up an oilfield in the near neighbourhood, and from the moment the drill opens up the sand, releasing the pressure, the holes drilled previously and not properly plugged become a real menace. Any well that has shown any trace of oil or gas should be effectively plugged upon abandonment. I was surprised to note recently on a certain oil field in the U.S.A. the carelessness with which a prolific oilsand was drilled through and left unprotected in the operators' haste to reach a lower and still more productive sand. In yet another field I noted wells had been drilled into bottom water within a large producing area, and that no precaution to shut this bottom water off had been taken, the result being a considerable amount of cut oil was being produced which had to be run into open sumps and burnt. There was not only the oil wastage, but the influx of water will make itself increasingly more apparent as the gas pressure become reduced.

In another field I was very surprised to see them landing strings of casing in shale and slate beds, which had to shut off waters

having from a few hundred to 2000 ft. head, without previously making any preparation or using either mud or cement. After the well was bailed down, the water broke in, the well was then drilled a few feet deeper and another test made. In one particular instance when they bailed the well they dumped the bailer contents between the last strings of casing, thereby hoping to seal off the water.

The following written contributions were subsequently received:

From **Mr. Ashley Carter.** Attention has on various occasions been drawn to waste in the oilfields; here surely is one of the most glaring examples to be met with; in fact, inattention by operators to this matter amounts to criminal negligence, because by inattention one operator may be the means of ruining a whole field, and too much prominence can never be given to this important subject.

The exclusion of water from oil-bearing formations is the crux of the science of drilling, not only to the well being drilled, but to the whole field. It is not possible to lay down any hard and fast rules on water shut off, as each case has to be dealt with strictly on its merits. Fortunately some fields are comparatively free from water trouble, but where it exists, it is a menace of far-reaching importance.

Before the introduction of cementing, packers, of which there is a large number of varieties, were used with success, and even at the present time are frequently employed, but it must be admitted they have not the life of cementing methods, which, moreover, serves the purpose of effective protection of the casing.

Whilst referring to casing, it should be stated that it is good practice to rotate the casing a few turns to distribute the cement on the outside before lowering the casing to the bottom of the well.

One important point suggested by the presentation of this paper is the necessity for intelligent and accurate logs being kept. The core drill will provide valuable information of the various strata passed through, and the probability is that this method will be more widely used in the future than has been the case in the immediate past.

It is disappointing that cement manufacturers did not take a greater part in the discussion, as whilst we know several ways of putting the cement into a hole, there is but little information available on the cement for the purpose under notice.

The effect of temperature on cement is a matter on which I would ask the author or cement experts to give us some information, and as a case in point mention a well where accurate temperatures were recorded. The temperature of the atmosphere at the surface was 80–85° F., at a depth of 600 ft.—the temperature was 92° F.,

and at 2000 ft.—108° F. What is the best cement for use at these temperatures, and what would be recommended for deeper wells with correspondingly higher temperatures? It would also be interesting to have particulars of special quick setting cement, such as "Ferrocrete," stating length of time at the various temperatures at which it sets and hardens.

From Mr. A. Frank Dabell. In a mechanical operation having for its sole aim the exclusion of water from a well by efficient contact being made between casing and formation, undue importance is generally attached to cement, which is an unnatural medium and should only be used as a last resort.

Clay, it has been shown, will penetrate farther than cement and is a better casing preservative.

By its plastic nature it will adapt itself to earth or casing movement and become more effective with superincumbent load irrespective of depth, temperature, etc.

Insertion of clay carries no mechanical risk, and if at first ineffective will often itself afford correction, and eventually permit the recovery of some or all of the casing with which it is in contact.

Where clay is not locally available its transport costs no more than cement.

Successful cementation is dependent upon a large number of factors, any of which may lead to disaster; to quote one usual experience—sudden failure of power in an electrically operated well at a critical moment.

For the insertion of clay the principle embodied in the Wallen system is the best, but the writer favours the omission of the wooden or metal shoe plug.

In this manner the casing, after being lifted off the bottom for a few lengths and the uncased portion of the bore filled with clay in solid form, is lowered sufficiently to obtain a piston of clay in its lower part and it is then filled with water and hermetically capped.

The column now becomes a ram and its weight the driving power.

This ram in its downward passage propels the inserted clay into and up the annulus formed between casing and rock until the column be seated.

The descending speed is regulated by giving release to water through a cock fitted to the casing head, allowing surplus clay to replace it below.

An important feature to remember by those using clay in a cold climate is that clay, once it has been frozen during exposure, has no further value for water shut off.

From Dr. O. Faber. The specification for cement given in the appendix is curious and could I think be improved upon.

In the first place it is difficult to see why it should be so much inferior to the British Standard Specification, which is generally recognised as being itself much too low for modern requirements. For example, the residue on a sieve of 5800 meshes to the square inch is specified not to exceed 10 per cent., yet the British Standard Specification limits this to 1 per cent. The British Standard Specification further limits the residue on a sieve of 32,400 meshes to the square inch to 14 per cent., a stipulation not referred to at all in the specification given. Actually the quick-hardening Ferrocrete previously referred to gives only 1 per cent. retained on this sieve of 32,400 meshes to the square inch and is therefore many hundred times finer than what is suggested in the specification. This would undoubtedly enable the cement to travel through strata which would be quite impervious to the coarse cement referred to in the specification, and add tremendously to its usefulness.

A figure of 400 lb. per sq. in. is required for the tensile strength in 7 days, although the British Standard Specification requires 450 lb. and the cement described in Part II. of the paper actually gave between 950 lb. and 1150 lb. It would therefore appear to be more consistent with best modern practice to put this at a figure quite considerably higher than 450 lb. In my own practice I have for many years specified a minimum of 600 lb. per sq. in., and for quick-hardening Ferrocrete there is no difficulty in specifying and obtaining cement in which 850 lb. per sq. in. is required.

The specification also stipulates that the strain shall be applied at the rate of 200 lb. per min., whereas the British Standard Specification specifies that the stress shall be applied at the rate of 100 lb. per sq. in. in 12 secs.

From **Mr. H. Keeble.** From the author's remarks, cement appears to play a very necessary part in shutting off water in oil well sinking, the physical and chemical properties of which being of considerable importance.

The first point which occurs to me is whether the usual tensile tests are in themselves sufficient to indicate the true qualities of the cement to be used, and whether the crushing tests should not be included. The reason for raising this point is, with ordinary Portland cement it has always been assumed, the ratio between tensile and crushing strengths was about 1–10, whereas it is found that with modern quick-hardening cements this ratio does not of necessity apply, it being in some cases as much as 1–13.

With regard to the various setting times given with cement, mixed with varying percentages of water, these are very interesting and conform to the generally accepted facts in this respect, *viz.*, the more water that is used for mixing, the longer the setting time,

but tests which appear to me very important have not been mentioned: they are the strengths of neat cement at different ages when mixed with varying large amounts of water.

From a very considerable number of tests made, especially by Professor Duff Abrams in America, it has been clearly demonstrated that after plasticity has been attained, the more water which is added, the weaker the resulting concrete or cement at all ages. Recent tests which have been carried out by well-known independent consulting engineers and testers have shown that the difference in strength between concretes mixed with 6 per cent. and 8½ per cent. water is approximately 50 per cent. at long as well as short periods, the greater strength being in favour of the lower water content. In this connection it would be interesting to know, therefore, what happens to the cement after it has been put into position in the well—does it remain as a liquid grout with a large excess of water, or is the excess water by pressure forced out of the cement and into the interstices of the strata, leaving the cement to set and harden as a solid mass?

Whether or not the cement is finally effective in keeping back the water would seem to me to depend very largely on this fact—in other words, whether the cementation process is effective or not depends very largely on the strength of the cement when the water pressure is allowed to re-act on it by bringing the well into use.

As regards the type of cement to be used, I agree with the speaker when he says that it would be slow setting, but quick hardening—slow setting so that there is time to get the cement into position before the initial set takes place, and quick hardening so that there is less time for secondary reactions to take place to disturb the cement whilst hardening, and also that important time may be saved in bringing the well into use.

Such a Portland cement is now being produced in large quantities in this country under the trade name of Ferrocrete. This cement has very quick hardening properties, its strength at 3 to 4 days is equal to a good average Portland cement at 28 days. It is also very finely ground and has an ultimate strength probably 50 per cent. greater than a good average Portland cement. Let me quote some figures taken from tests recently made by Messrs. Riley, Harbord and Law on Ferrocrete both in tension and compression.

By using such a cement water pressure can be allowed on it after four or five days instead of the usual three or four weeks. This means that an equivalent time can be saved in bringing the well into operation.

Rapid-Hardening Ferrocrete.

Certificate of Compression Tests made on six inch Concrete Cubes, made by Us.

Four parts Ham River Ballast, 2 parts Ham River Sand, 1 part Rapid Hardening Ferrocrete.

Percentage of water used, 6 per cent.

Age of Cubes.	24 hours. lb. per sq. in.	2 days. lb. per sq. in.	3 days. lb. per sq. in.	5 days. lb. per sq. in.	7 days. lb. per sq. in.	28 days. lb. per sq. in.
	1730	3220	3400	4640	5320	6830
	1710	2640	4220	4970	5280	6420
	1820	2880	3940	4920	5580	7190
Mean ..	1750	2910	3853	4840	5360	6810

Certificate of Tensile Tests on Rapid Hardening Ferrocrete Portland Cement.

Mechanical Tests.

1 part 3 parts Age of briquettes	Cement and Sand. 1 day.	Cement and Sand. 2 days.	Cement and Sand. 3 days.	Cement and Sand. 5 days.	Cement 7 days.	Cement and Sand. 7 days.	Cement 28 days.	Cement and Sand. 28 days.
	340	555	620	640	1020	695	1105	695
	300	525	615	610	1015	720	1025	735
Results of	325	485	570	635	1010	685	1055	710
tests in lb.	295	540	565	600	920	665	1120	715
per sq. in.	280	490	580	580	905	665	1040	720
	330	500	550	600	995	700	1115	705
Mean strength	312	516	583	611	977	688	1077	713
Specified mean strength not less than ..					450	200	539	250

Sieve and Expansion Tests, Setting Times, etc.

Percentage left on sieve, 5,776 meshes to the sq. in.		Specified	Not to exceed 1·0%
		Actual	0·02%
" " 32,400 " " "		Specified	14·0%
		Actual	0·30%
Setting time (initial) ..	Specified not less than	Quick.	Slow.
	Actual	2 mins.	20 mins.
			1 hr. 10 mins.
Setting time (final) ..	Specified not more than	30 mins.	10 hours.
	Actual		2 hr. 20 mins.
		24 hours.	7 days.
Expansion	Specified not to exceed	10 m.m.	5 m.m.
	Actual	1 m.m.	

As showing the quick hardening properties of this cement, it may be stated there are many instances where piles only seven days old have been driven successfully when made with it; with ordinary cement such piles would require to mature a month or six weeks before driving. Concrete roads made with it have

borne heavy traffic within 48 hours of laying, without any deleterious effect. Many other such instances could be quoted.

What action waters having different chemical constituents encountered in oil well sinking would have upon the rate of hardening of such a cement remains to be proved, but this could be very quickly and easily ascertained. The British Portland Cement Association offer such facilities gratis.

A still more rapid hardening cement produced in this country is the Aluminous Cement sold under the trade name of "Lightning" Brand. This is not a Portland Cement, but has Bauxite as one of the principal raw materials from which it is made. Owing to its costly manufacture, however, this cement is much more expensive than Ferrocrete, and still more so than ordinary cement.

Just as Ferrocrete, the quick hardening Portland Cement, is revolutionising many cement using industries in this country, so should it have an important effect upon the use of cement for shutting off water in oil wells. Whether its quick hardening properties would be affected by the peculiar conditions in an oil well remains to be proved.

A speaker has asked what effect the high temperatures encountered would have on the setting time of Ferrocrete—the answer is the same as ordinary Portland Cement, viz, the higher the temperature the quicker the setting, but it is very doubtful if the temperature encountered would have sufficient effect to render Ferrocrete (a slow setting cement)—quick setting.

Mr. Rappoport, in replying, hoped that other papers on this important subject might be forthcoming from members. There must be many problems the solution of which must have required thought and skill, and of which detailed accounts would be interesting and useful. He himself had only dealt with the subject in a general and introductory way.

Turning to the discussion, and first in reply to the President, his remarks would be appreciated by those who had had to do with water trouble in the field. In particular those remarks dealing with the function of the Geologist in regard to the particular matter which was the subject of this paper.

He fully agreed with what the President had said about legislation for water trouble, and particularly his insistence upon the elucidation of the principles upon which to base such legislation. A scientific, and necessarily progressive matter of this kind, might easily be hampered by hard and fast regulations. The author had had experience of the restrictive type of legislation, and of the evils following it. The law for water shut off ought to be laid down on broad lines, interpreted broadly with due regard to security, and applied by broad-minded officials. In this respect the system in

Burmah was, in the author's experience, one of the most practical. The regulations themselves were a few short paragraphs enunciating general principles. These were applied by a Government Warden with the assistance of a committee of field managers. In this way any difficulties or proposals for dealing with such difficulties were considered by practical men in whose views the Warden could have confidence. By this means the spirit, rather than the letter, of the law was applied.

In reply to Prof. Nash, there was possibly a tendency on the part of smaller and less experienced Companies not to realise the danger of inadequate water shut off methods. The author's remarks on Legislation in reply to the President would apply here. He agreed with Prof. Nash about the desirability of having a central Government station for the purpose of collecting and collating all technical information on the field, and of its dissemination. The case of Burmah in regard to water shut off precautions might again be quoted as an illustration. All such information must be supplied to the Warden, and this is primarily treated as confidential, but the Warden has discretionary powers to communicate this information to others if, in his opinion, it is essential to the protection of the oil sands from flooding that he should do so.

The colour test was useful where positive results were obtained, but it was not a sure test in the case of negative results, as then matters were left in much the same position as before the test.

He did not agree with Prof. Nash that a cement suitable for harbour work would be equally suitable for oil field work. He thought that the cement should be specially prepared not only to suit general oil field conditions, but, in some cases, to suit any special conditions that might arise. The principal general requirement for such a cement was the one stated in the paper, to have a slow intitial setting time, but a quick hardening period. In this connection he would draw attention to Mr. Keeble's contribution to the discussion.

The most adequate test was to bail the well dry, and in some countries this was the prescribed test after a water shut off had been made. In the cases of deep wells, or when the quality of the casing was in doubt, there was a reluctance to empty the well entirely of liquid for fear of causing damage to the casing.

There is still a good deal of uncertainty about the precise plastering effect that the mud produces on the walls of the well, but he would refer Prof. Nash to Mr. A. Knaap's paper to the American Inst. of Min. & Met. of February, 1923, where a most interesting investigation on this subject is described. Mr. Harold Dabell's contribution to this discussion is a good illustration of the effect of mud.

A factor of safety based on the elastic limit, or better even on the fatigue limit, would certainly be preferable from an engineering point of view. It might, however, mean at least doubling all thicknesses of pipe in common use at the present time, or halving the lengths to which pipes of the scantlings given in the tables based on Stewart's formula should be carried. This would mean considerable expense. One had to consider whether for a minority of bad cases one would go to the expense of altering scantlings which in the majority of cases had proved suitable. Although the engineering soundness of this was open to question economic expediency had also to be considered. In particularly bad cases special casing might be used.

In reply to Mr. Penny he agreed as to the danger to casing from the corrosive action of certain waters. The use of mud fluid plastered on the casing mitigated this danger. Cementation might also do so, but in some cases the cement might not rise high enough to afford complete protection.

He had dealt with the staining test in his reply to Prof. Nash.

Formation shut offs, when applicable, had many advantages undoubtedly, and the same applied to the use of clay instead of cement. Thus a string of casing could rarely be freed after a cementation, and the use required more appliances and care in handling.

Mr. Penny had amplified the author's account of the Wallen water shut off method, and Mr. Frank Dabell, in his written communication, had also dealt with this method. This system had been in practical use for a long time in the Grosny field, where it was particularly adaptable.

In reply to Mr. Dewhurst, whose remarks were an interesting contribution to the discussion, the description of what occurred at the oil water boundary in the sand was particularly interesting.

He agreed with Mr. Dewhurst in regard to the dangers of group production, as the edge water originally confined to one stratum might eventually become tap water in relation to the lower lying oil source, against which, under this system of group production, no precautions would have been taken.

The Bradford field was the historic case where flooding the oil sands, thus emulating the action of edge water under natural conditions, was resorted to for the first time. It was understood to be a remedy applicable to a field in the last stages of exhaustion, *i.e.*, in which the gas was exhausted and so the oil remaining in the sand had no more motive power. It was an interesting fact that the entry of tap water as described by Mr. Dewhurst into the lower producing sands first raised the idea of adopting such a system as a means of driving oil out of apparently exhausted sands.

He fully concurred with Mr. Dewhurst in the advisability of making the water shut off as near the producing sand as possible. This afforded a maximum of protection for individual wells, and so for the oil field.

Replying to Mr. Charles Dabell, and dealing with the case where an improvement in production was noticeable in the wells at Grosny after a prolonged stoppage, he thought that this might be alternatively explained thus: Where there is much water with the oil, as was the case in Grosny, intensive bailing tends to draw up the water, a water cone being formed at the entry to the well. This cone tended to cut off the overlying oil. With relaxation of production the cone would tend to subside, and so allow more oil to come in. This oil would appear on resuming exploitation. The improvement would probably not last long in such water-logged horizons, and it would therefore be interesting to hear what the subsequent experience in this matter actually was.

Regarding the point, touched upon by Mr. Dabell, that of the relations of the larger Companies in an oil field towards the lesser ones on such matters as those of the subject of this paper, he felt that such a policy was too short sighted a one to be pursued for long in present times by either large or small Companies. With an impartial Government official on the spot any questions of this kind ought to be adjusted easily, even if the common sense of both parties did not effect it. It was in this respect that he still felt, as he had stated in the paper, that greater co-operation had been established among workers on the field than was formerly the case.

In reply to Mr. Harold Dabell, the experience described shows the value of mud in closing fissures. The method of pumping the mud back through the well into the fissures, against the natural head of water, is novel and interesting.

In reply to Mr. Albert Millar's written communication:—

Experience has shown that, where water and oil are together in the same stratum, intensive production draws in the water, and in so doing traps out the oil. This was the case in the Baku field in using large bailers, or in the excessive application of the air lift. It is borne out by Mr. Millar's remarks on the use of the swab in the Galician field.

Mr. Millar's statement of the improvement in production in Galicia after a stoppage is similar to the case mentioned by Mr. Charles Dabell in the case of Grosny, the explanation suggested by the author in his reply to the latter being possibly the same in both cases.

Anything that may increase the strength of casing, and so the factor of safety, without unduly increasing the weight or cost, is

to be recommended. The use of solid drawn casing, mentioned by Mr. Millar, is a case in point. Distortion is difficult to prevent when casing has to be carried long distances from the works to the field. It is, of course, a source of weakness, and is a further draught on the already all too low factor of safety.

Mr. Millar's accounts of American cementation, the use of mud, the plugging of wells, form interesting and valuable additions to the paper, especially following Mr. Millar's recent stay in the American fields.

In reply to Mr. Neelands, the 40 per cent. of mixing water is not that percentage of the total (water—oil), but is 40 per cent. of the quality of cement used. This is the usual oil field custom for obtaining these proportions. In terms of the total the percentage would be about 28 per cent. water and 72 per cent. cement. It has been found that this proportion gives the necessary fluidity for flowing down small tubes, say 2 in. or 3 in.

Some of the pumps used are given in the paper. The sludge pumps used in rotary drilling are also applied to cementation, if necessary. These pumps are about $10\times6\times10$ or $12\times7\times14$.

The quantity of cement used must depend upon such factors as the volume of the annular space between the wall of the well and the casing, and upon the distance that it is required the cement should rise. A rough general calculation is given by one of the authorities (Tough, Bureau of Mines Bulletin No. 163).

10 in. casing	..	6 to 12 tons.
8¼ in. „	..	4 to 8 „
6¼ in. „	..	3 to 7 „
4½ in. „	..	2 to 4 „

This assumes casing at least 1500 ft. from the surface.

By some of the methods described in the paper the grout is carefully protected from coming into contact with large volumes of water during its passage down. At its point of application, however, *i.e.*, when the grout is about to be forced up behind the casing, it must necessarily come into contact with the water in the well itself, and this would have the effect of retarding the setting point of the grout. It is, however, at this point that the mass is also subject to the greatest pressure. As these grouts do actually harden properly in many cases, the pressure appears to neutralise the bad effect in the retardation of the setting point. The point is an interesting one, and the author is obliged to Mr. Neelands for having drawn attention to it.

The difficulty with regard to the suggestion of making protective cementations at certain distances from the borehole, as in mining, would be the prohibitive cost, on account of the great depths involved in oil well drilling.

The mechanical processes described may seem elaborate, but not unnecessarily so when account is taken of the conditions, the work being conducted out of sight from the surface, and at distances down of from 1000 to 3000 ft., and through holes of from 6 in. to 10 in. in diameter. Acutally, however, most of the methods in use are simple and straightforward in practice.

The author agrees with Mr. Frank Dabell as to the desirability of using clay for water shut off, or for making formation shut off whenever possible. With the advancing use of mud, and its proven suitability for clogging up sand pores, it is quite possible that clay for water shut off may be more largely used in the future. An advantage of cement over clay in some cases is the better support it gives to the casing.

Replying to Mr. Ashley Carter's written communication, a note of the effect, in general, of temperature on the setting property of cement is given in the paper. In Venezuela wells with hot water (up to 127° F.) have been successfully cemented, but the author does not know if any special brand of cement was used for this purpose. Oatman gives the following experimental data showing the effect of increased temperatures :—

	84° F.	110° F.	142° F.
Initial set (hours)	.. 6	.. 3½	.. 2½
Final set (hours)	.. 8	.. 5½	.. 3¾

In reply to Dr. Faber's written communication, the specification was the one for cements used on the Russian oil fields, and as made by the Russian cement factories. It suited the requirements for cementations as carried out on the Baku oil fields. It is, of course, capable of modification, and the author is obliged to Dr. Faber for his suggestions in this respect.

In reply to Mr. H. Keeble, there is no certainty of what does actually happen to the grout when it has been placed in position in the well, the surmise being that, under the pressure exerted, a certain amount of the cement will be forced into the interstices of the strata, this forming the connection to the solid ring of cement which it is expected will form between the wall of the well and the outside of the casing. There is always an element of uncertainity in the matter, as by no means all cementations for water shut off are successful.

The author's attention had already been drawn to the particular brand of cement called Ferrocrete, and the data and figures supplied by Mr. Keeble are of considerable interest. One would say that this cement ought to give good results on the oil fields, and is worthy of trial.

The resolution of thanks to the author for his valuable paper was then put and carried by acclamation.

The Measurement of Viscosity by the Ostwald Viscometer; Conversion to Time by the Redwood Viscometer.

By Sidney T. Minchin, B.Sc.

Introduction.

The present paper discusses the practicability and the advantage of the use of Ostwald viscometers for routine oil testing.

Although the adoption of absolute units for the measurement of the viscosity of oils has often been advocated, the habit of the trade to think in terms of "Redwood Seconds" has become deeply rooted; and, whilst the scientific objections to all that the term involves may be admitted, it is nevertheless true that it fulfils all ordinary practical requirements.

The determination of the viscosity in terms of Redwood Seconds of a large number of samples of oils being required, it was felt that an economy of time might be effected by the use of Ostwald viscometers and subsequent conversion of the results obtained. Further, samples received or obtained in the course of research are frequently insufficient in quantity for a determination of viscosity by the Redwood instrument.

It was decided to obtain a sufficient number of Ostwald viscometers to enable oils of the whole range met with in the trade to be dealt with in a time long enough for some of the correction terms to be small, but not unduly prolonged. The limits of Redwood seconds were fixed at 35 and 2000, and of Ostwald seconds 100—300. Calculations shown below *in extenso* indicate that the range can be covered, allowing ample margin for overlapping and errors in construction, by a set of seven Ostwald viscometers, all dimensions (except radius of capillary) being as near as possible to those given in Fig. 1.

The results obtained show:—

(1) That the time required for determination of viscosity by the Ostwald viscometer is considerably less than by the Redwood apparatus, especially when a number of determinations are made at one time.

(2) That the accuracy of the results obtained in Redwood seconds by conversion from absolute units is equal to that of results obtained direct, but an important advantage is that while it is difficult to maintain oil contained in a Redwood viscometer at a constant temperature for an extended period, the Ostwald tubes contained in a thermostat can be maintained without difficulty within 0·1° F. of the temperature required. Hence the liability to error is probably actually less than that by the direct method.

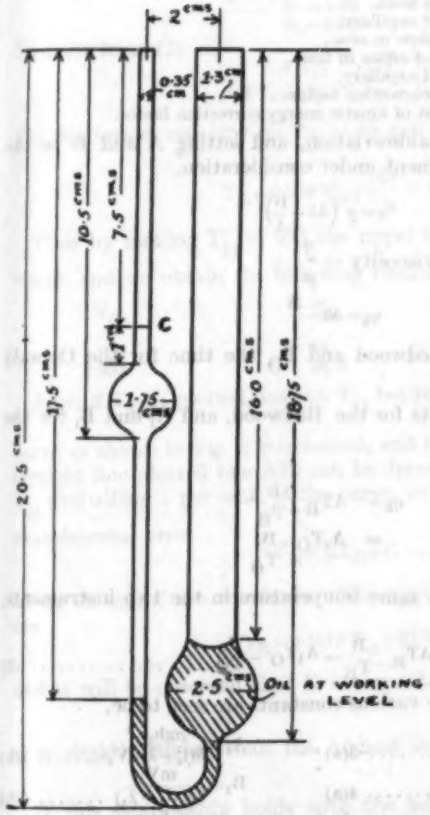

FIG. 1.

FIG. 1 (a).

It has not been found possible to use the Ostwald viscometers with black asphaltic oils, as the marks on the tube are obscured by such oils.

Theoretical.

The modified form of Poiseuille's equation for the ordinary type of gravity flow viscometer can be written :—

$$\eta = \frac{\pi\rho g h r^4 t}{8\,(l+\lambda)\,V} - \frac{m\rho V}{8\pi t\,(l+\lambda)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where η = absolute viscosity,
ρ = density at the temperature under consideration,
h = effective head,
r = radius of capillary,
t = time of flow in secs.,
V = volume of efflux in time,
l = length of capillary,
λ = Couette correction factor,
m = coefficient of kinetic energy correction factor.

Adopting the usual abbreviation, and letting A and B be the constants of the instrument under consideration,

$$\eta = \rho\left(At - \frac{B}{t}\right)$$

and if η_k = kinematic viscosity $= \dfrac{\eta}{\rho}$

$$\eta_k = At - \frac{B}{t}$$

Let T_R be the time Redwood and T_O the time for the Ostwald viscometer.

A and B the constants for the Redwood, and A_1 and B_1 for the Ostwald ;

then

$$\eta_k = AT_R - \frac{B}{T_R} = A_1T_O - \frac{B_1}{T_O}$$

for the same oil at the same temperature in the two instruments, so that

$$AT_R - \frac{B}{T_R} = A_1T_O - \frac{B_1}{TO} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

From expression (1) the various constants are seen to be,

$$A = \frac{\pi g h r^4}{8\,(l+\lambda)\,V} \quad \ldots\ldots 3(a) \qquad A_1 = \frac{\pi g h_1 r_1^4}{8(l_1+\lambda_1)\,V_1} \quad \ldots\ldots 3(b)$$

$$B = \frac{mV}{8\pi\,(l+\lambda)} \quad \ldots\ldots 4(a) \qquad B_1 = \frac{mV_1}{8\pi\,(l_1+\lambda_1)} \quad \ldots\ldots 4(b)$$

In order to cover the range of viscosities decided upon, the radius of the capillary in the Ostwald tube is varied, the other measure-

ments being kept as nearly constant as possible. It has been stated that the limits of times in the Ostwald tubes were taken between 100 and 300 seconds. Below 100 seconds the correction term $\frac{B_1}{T_O}$ becomes an appreciable quantity, while 300 seconds is a reasonable maximum time.

Hence the values of the constants can be approximately evaluated, with the exception of A_1.

$$A = 0{\cdot}0026$$
$$B = 1{\cdot}88$$
$$B_1 = 0{\cdot}195$$

So that, from (2)

$$T_R = \frac{A_1 T_O}{0{\cdot}0026} + \frac{723}{T_R} - \frac{74{\cdot}0}{T_O} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

For the lowest viscosity oil $T_R = 35$ and $T_O = 100$, whence

$$T_R = 0{\cdot}148\, T_O + \frac{723}{T_R} - \frac{74{\cdot}0}{T_O}$$

Thus by making $T_O = 300$ the upper limit of this tube can be found, and we obtain the following results :—

T_O	T_R	$\frac{723}{T_R} - \frac{74{\cdot}0}{T_O}$
100	35	20·2
300	56·5	12·7

Now, if T_R is plotted against T_O between $T_O = 100$ and 300 a curve as shown in Fig. 2 is obtained, and it will be observed that a straight line (dotted line AB) can be drawn which gives values for T_R well within 1 per cent. of the curve, so that within the limits of experimental error,

$$T_R = KT_O + C \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

where K and C are constants. The approximate values of these are

$$T_R = 0{\cdot}1075\, T_O + 23{\cdot}7,$$

and it will be observed that K is somewhat less than $\frac{A_1}{0{\cdot}0026}$ and C is slightly higher than the highest value of $\frac{723}{T_R} - \frac{74{\cdot}8}{T_O}$

If this relationship holds with the tube of smallest capillary used, it will obviously be more correct as T_R increases.

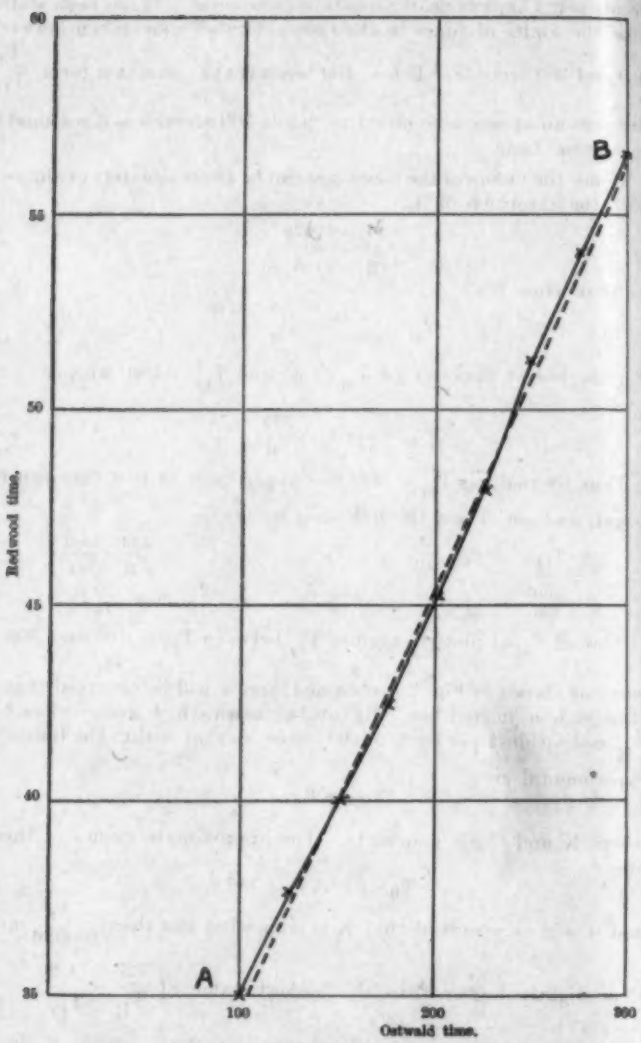

FIG. 2.

As T_R increases the term $\frac{723}{T_R}$ decreases, and at a certain value of T_R will be less than 1 per cent. of T_R. At this point

$$T_R = \sqrt{723 \times 100}$$
$$= 270 \text{ approx,}$$

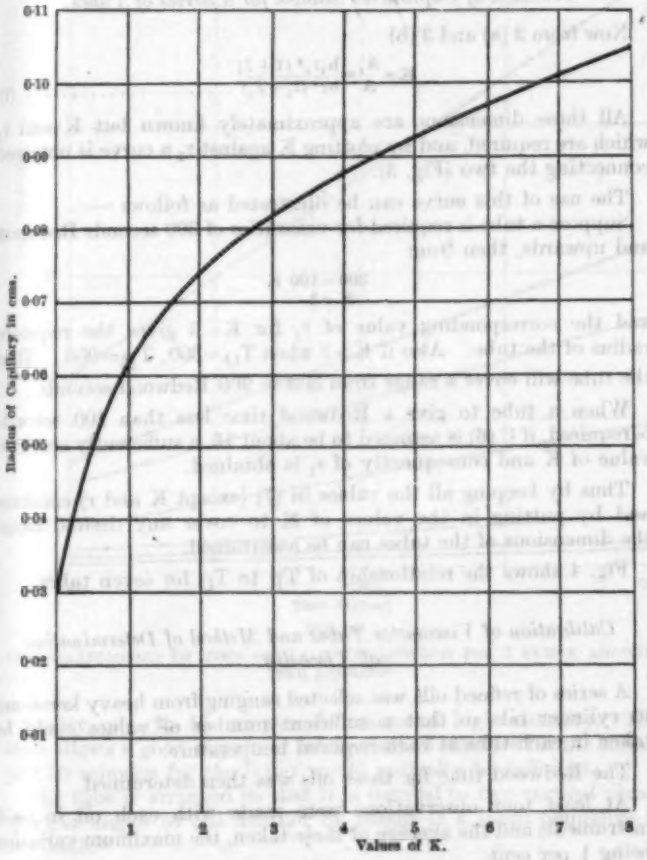

FIG. 3.

CURVE FOR OBTAINING THE RADIUS OF CAPILLARY WITH DIFFERENT VALUES OF K.

and the necessity for a constant will vanish, so above this point (K=2·7) the relationship is

$$T_R = KT_O$$

Hence over the range of viscosities considered T_R is a linear function of T_O.

Selection of Capillaries suitable for a Series of Tubes.

Now from 3 (a) and 3 (b)

$$K = \frac{A_1}{A} = \frac{h_1 r_1^4 (1+\lambda)}{h r^4 (l_1+\lambda_1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

All these dimensions are approximately known but K and r_1 which are required, and by plotting K against r_1 a curve is obtained connecting the two (Fig. 3).

The use of this curve can be illustrated as follows :—

Suppose a tube is required for viscosities of 300 seconds Redwood and upwards, then from

$$300 = 100\ K$$
$$K = 3$$

and the corresponding value of r_1 for K=3 gives the requisite radius of the tube. Also if K=3 when T_O=300, T_R=900. Thus the tube will cover a range from 300 to 900 Redwood seconds.

When a tube to give a Redwood time less than 100 seconds is required, if C (6) is assumed to be about 15, a sufficiently accurate value of K and consequently of r_1 is obtained.

Thus by keeping all the values in (7) (except K and r) constant and by putting in the values of K to cover any desired range the dimensions of the tubes can be ascertained.

Fig. 4 shows the relationship of T_R to T_O for seven tubes.

Calibration of Viscometer Tubes and Method of Determination of Viscosity.

A series of refined oils was selected ranging from heavy kerosenes to cylinder oils so that a sufficient number of values could be taken in each tube at each required temperature.

The Redwood time for these oils was then determined.

At least four observations were made with each oil in each instrument, and the average of these taken, the maximum variation being 1 per cent.

In this way determinations were made at 70° F., 100° F., 140° F., 200° F.

All the oils used for calibration were filtered through calcium chloride, as the presence either of small solid particles or of water may cause very large errors.

The tube is filled well over the working volumes (indicated below) and placed in the bath for a time ranging from 20 minutes, for low

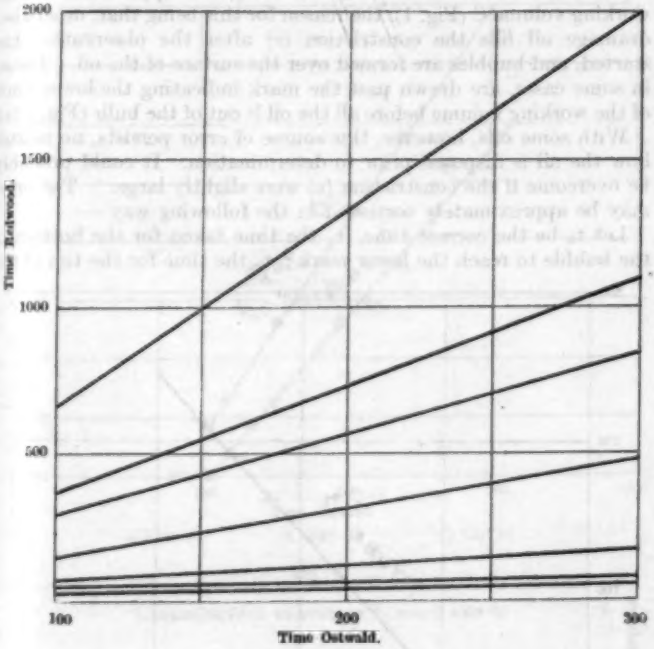

FIG. 4.

THE RELATIONSHIP OF TIME OSTWALD TO REDWOOD FOR 7 TUBES, SHOWING THE OVERLAP.

viscosity oils, to 45 minutes for those of high viscosity. This time allows a good margin of safety, and 15 minutes for the former and 30 minutes for the latter would normally be sufficient.

The tube is arranged so that it is parallel to two vertical planes at right angles to one another by means of a small plumbline in the bath.*

* Barr, *Jour. Sci. Inst.*, 1, 112.
B.E.S.A. Report on The Determination of Absolute Viscosity by Means of Capillary Tubes.

Oil is sucked out of the wider tube by means of a pipette so that the level of the oil is just up to the shoulders of the lower bulb (Fig. 1). The tube is left for a few minutes, and any drainage oil removed.

The oil is then sucked up the capillary limb so that it is not more than 0·5 cm. above the mark indicating the upper limit of the working volume C (Fig. 1), the reason for this being that, otherwise, drainage oil fills the constriction (c) after the observation has started, and bubbles are formed over the surface of the oil. These, in some cases, are drawn past the mark indicating the lower limit of the working volume before all the oil is out of the bulb (Fig. 1 (a).

With some oils, however, this source of error persists, no matter how the oil is disposed prior to determination. It could probably be overcome if the constriction (c) were slightly larger. The error may be approximately corrected in the following way :—

Let t_k be the correct time, t_a the time taken for the bottom of the bubble to reach the lower mark ; t_b the time for the top of the

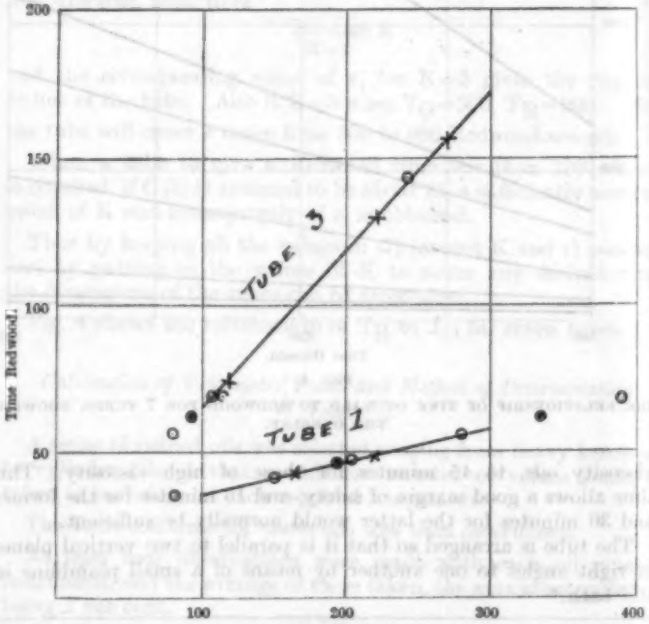

FIG. 5.

EXPERIMENTAL CURVE OF TUBES 1 AND 3.

bubble to reach the lower mark; t_c the time required for the bubble and all the oil to pass this mark (each time being taken from the commencement), then

$$t_R = t_a + (t_c - t_b).$$

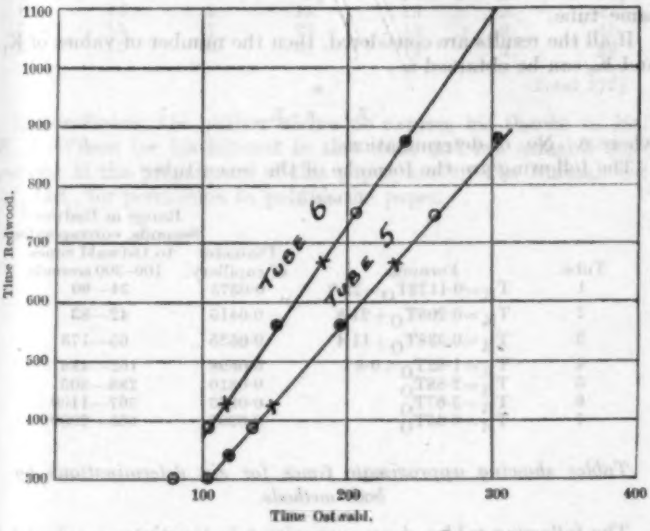

FIG. 6.

EXPERIMENTAL CURVES OF TUBES 5 AND 6.

The results obtained at all temperatures investigated for several tubles are shown on curves by plotting T_R against T_O (Figs. 5 and 6); and it will be seen that these points fall on a straight line. Thus one curve or formula applies for one tube at all temperatures.*

The advantage of this is evident since a tube standardised at three (or more) temperatures can be used anywhere within the limits of the temperature of standardisation with certainty.

The constants given in the formulæ 5, 6, 7 (Table 1) are calculated from the slopes of the various curves.

* Barr, *Rept. Aero. Res. Com.*, No. 906, p. 10.

With tubes Nos. 1, 2, 3, 4 the equations are obtained by solving the following simultaneous equations for K_1 and K_2:—

$$T_R = K_1 T_O + K_2$$
$$T^1_R = K_1 T^1_O + K_2,$$

where T_R; T^1_R; T_O; T^1_O are the times for two different oils in the same tube.

If all the results are considered, then the number of values of K_1 and K_2 can be obtained is

$$\frac{n}{2}, \frac{n-2}{}$$

where n = No. of determinations.

The following are the formulæ of the seven tubes:—

TABLE I.

Tube.	Formula.	Diameter of capillary.	Range in Redwood Seconds, corresponding to Ostwald times 100–300 seconds.
1	$T_R = 0{\cdot}1173T_O - 22{\cdot}7$	0·0375	34—60
2	$T_R = 0{\cdot}205T_O + 21{\cdot}8$	0·0415	42—83
3	$T_R = 0{\cdot}538T_O + 11{\cdot}4$	0·0525	65—173
4	$T_R = 1{\cdot}62T_O + 0{\cdot}8$	0·0698	162—486
5	$T_R = 2{\cdot}88T_O$	0·0810	288—805
6	$T_R = 3{\cdot}67T_O$	0·0863	367—1100
7	$T_R = 6{\cdot}65T_O$	0·0997	665—2000

Tables showing approximate times for six determinations by both methods.

The following tables show approximately the times required for determinations of six oils by both methods.

In the case of the Ostwald method, Tubes 1 and 7 were placed together in the bath at 70° F., and the samples quoted below determined in pairs, *e.g.*, C with H, etc. A further economy in time is accomplished by immersing the oils awaiting determination in thin-walled bottles in the bath, by clamping them to a shelf at the back of the thermostat, but no allowance has been made for this.

OSTWALD VISCOMETERS.

Sample.	Preliminary heating.	Levelling of instrument, etc.	Time for two determinations.	Time between two determinations.	Time for cleaning.	Total time for each tube.	Det. in pairs as numbered.	Time for two determinations. Minutes.
C } 1	10	3	7	3	3	26	1	C and H 40
D } 1	10	3	9	3	3	28	2	D and I 45
E }	10	3	13	3	3	32	3	E and J 45
H }	25	4	2	3	4	38	1	
I } 7	25	4	4	3	4	40	2	Total, 130
J }	25	4	6½	3	4	42½	3	minutes

REDWOOD VISCOMETERS.

Sample.	Preliminary Heating.	Levelling of liquid, etc.	Time for two determinations.	Time between two determinations.	Cleaning.	Total time for each.
C	10	2	2	10	2	26
D	10	2	2	10	2	26
E	10	2	2½	10	2	26½
H	15	2	13	15	2	47
I	15	2	25	15	2	61
J	15	2	52	15	2	86
					Total	272½

In conclusion, the author wishes to express his thanks to Mr. W. J. Wilson for his interest in this work and for valuable suggestions in the preparation of this paper, and to The Burmah Oil Co., Ltd., for permission to publish the paper.

Suggested Origin of the Oil-Bearing Strata of Burmah, deduced from the Geological History of the Country during Tertiary Times.

By Murray Stuart, D.Sc., Ph.D., F.G.S., F.C.S.

The geological history of Burmah during Tertiary times was determined mainly by the intense earth movements of the period, which in many parts of the world caused portions of the sea floor of Eocene times to become upheaved and its consolidated strata bent up along several lines into those immense crust-wrinkles which now constitute some of the grandest of the Eurasian mountain-chains, the finest examples of which are the Himalayas and the Alps. The Arakan Yoma range in Burmah, although comparatively insignificant when compared with the more imposing mountain-chains of the world, was elevated during the same great mountain-making epoch, and the material derived from it by denudation and erosion during its elevation contributed to the formation of the post Eocene strata of Burmah.

In India and Burmah three main phases can be distinguished in this great mountain-making upheaval during which the movement was more intense than at other times. The first main phase occurred towards the end of the Eocene, the second about the middle of the Miocene, and the third and last in Middle or Upper Pliocene times. Before the beginning of the movement the old Chinese mainland, which included most of what is now the Shan States and the North-East Frontier Division of Burmah, was bounded on the west by open sea, which was continuous with the Tethys or great Mediterranean sea of those times. The first main phase of the Himalayan movement extensively folded the Eocene and underlying strata, and uplifted them along the lines of the Himalayas and Arakan Yomas into ranges of considerable altitude, without however obliterating either the Tethys or the open sea west of China, which still retained their continuity. The geographical conditions at the end of the first main phase of the movement were therefore as follows: the Himalayan range had been elevated above sea level, but was separated from Peninsular India by a portion of the Tethys, and at the same time the Arakan Yomas had been ridged up and formed a long narrow island which did not extend sufficiently far north to be continuous with the Himalayas. The fact that the Arakan Yomas and the Himalayas were not

continuous at this period was established in 1921, when a geological traverse made by the author from Ledo in Upper Assam, through the Hukong Valley, into Burmah, revealed the fact that the Patkai range, which is the present northern extension of the Arakan Yomas, consists of a syncline of Tipam sandstones, which are not considered as being older than Miocene in age.[1] Between the Arakan Yoma Island and the Chinese mainland an arm of the sea remained, which was continuous in the north with the Tethys. If what is now the Brahmaputra river had commenced its existence at this time, as is quite possible, its sediments would have been deposited on both flanks of the northern end of the Arakan Yoma Island, and this may account for the similarity between the sedimentary strata of that age in Upper Assam and those of the Chindwin districts of Upper Burmah.

The second main phase of the Himalayan movement in Middle Miocene times, not only further uplifted the Arakan Yoma range, but also upheaved and folded the strata that had been accumulating at the bottom of the sea between the Arakan Yoma Island and the Chinese mainland, and either cut up this arm of the sea into disconnected lagoons and inland seas, or as seems more probable reduced it to a shallow gulf.

The third and last main phase of the movement, in Middle or Upper Pliocene times, still further elevated the Arakan Yomas, and established land conditions between them and the Chinese mainland. Precisely when elevation caused the junction of the Arakan Yoma Island with the Himalayas is not yet clear. The question would appear to depend on the age of the Tipam sandstones. These are regarded by some as being the equivalents of the Irrawaddy sandstones of Burmah, and by others as being more likely to be of Pegu age. The author inclines towards the latter view. It would appear, however, that the junction could not have taken place before the time of the second main phase of the Himalayan uplift, and consequently the question of when it did occur precisely has little or no effect on the matters discussed in the present paper.

In the interval between the first and second main phases of the Himalayan uplift, a great thickness of sediments was deposited over the floor of the arm of the sea which existed between the Arakan Yoma Island and the old Chinese mainland. These sediments form the strata which are now grouped together geologically under the name of the Pegu system of Burmah, and contain the important oil-bearing strata of the country. Between the second and third main phases of the uplift a thickness of sands and gravels was deposited over the same area overlying the strata

[1] *Rec. Geol. Surv. Ind.*, Vol. LIV., part 4, p. 402 (1923).

which constitute the Pagu system. These sands and gravels are now grouped geologically under the name of the Irrawaddy system.

At the end of the first main phase of the uplift the newly elevated Arakan Yoma Island became subjected to the action of denudation and erosion. Moreover these geological agents must have been more active there than they would be in the case of an old land surface on which they had been operating for a considerable period of time, and which in consequence of their action had had most of its steeper gradients worn down. As the Arakan Yoma Island was continually being elevated it seems reasonable to suppose that the major part of the material now forming the strata of the Pegu system was derived originally from it as a result of denudation and erosion acting upon it. The same reasoning applies to the period between the second and third main phases of the uplift, and it seems equally reasonable to suppose that most of the material now forming the Irrawaddy system of Burmah was also derived from the denudation and erosion of the Arakan Yomas. A certain amount of sediment would be derived from the old Chinese mainland of course, and, during Pegu times at least, a certain amount of sediment probably came from the north from what possibly corresponded to the upper reaches of the present Brahmaputra river, but undoubtedly most of the material now forming the Pegu and Irrawaddy systems of Burmah would appear to have been derived from the Arakan Yomas.

If this assumption is granted then it is to the ancient Arakan Yoma Island that one must look, probably, for the explanation of the existence of oil-bearing strata in the Pegu system of Burmah.

In 1910 the author proved by experiment that naturally occurring oil need not necessarily have been formed in the series of strata in which it is now found, but that it is possible for oil, as oil, to be a sedimentary deposit.[3] This opened up the possibility that the oil now found in the Pegu system of Burmah may have been equally as much a sedimentary deposit as the particles of clay and sand that go to make up the deposits, and that its original formation may have taken place elsewhere. Before this possibility was demonstrated the genrally accepted view was that the oil is the decomposition product of organic material, partly or wholly of vegetable origin, which was entombed in the rocks when they were deposited; slow distillation of the organic matter at low temperature, and bacterial action under water and therefore in the absence of air, being generally considered to have been the agents of transformation. There is an argument against this latter suggestion being the true explanation of the origin of the oil in the Pegu

[3] *Rec. Geol. Surv. Ind.*, Vol. XL., part 4, 321–333 (1910).

system of Burmah. In many parts of Burmah seams of lignite occur in the upper beds of the Eocene, comparatively close below oil bearing strata belonging to the Pegu system. If the origin of the oil were due to the transformation of organic material which was entombed in the rocks when they were deposited, one would expect the same agents of transformation to have affected the seams of organic material that now form the seams of lignite in the Upper Eocene of Burmah, since all these strata must have been subjected to much the same conditions since the time of their deposition. The fact that the organic material deposited in the upper strata of the Eocene of Burmah has formed normal lignites makes it seem unlikely that organic material deposited in the overlying Pegu system should have been transformed completely into oil and gas. In any case it seems reasonable to assume that the hydrocarbon compounds now occurring in the Pegu strata in the form of mineral oil came originally from the Arakan Yoma Island in some form or another, and were deposited in either a liquid or a solid form, incorporated as an integral part of the Pegu sediments.

The Pegu system consists almost entirely of marine beds of clay, shale, and sandstone, amongst which oil-bearing strata occur. It does not contain any marked preponderance of siliceous sedimentary rocks. The overlying Irrawaddy system consists of fresh water, false bedded sandstones, and conglomerates, and is characterized by the presence in it of vast quantities of silicified wood. It is essentially a system of siliceous sedimentary rocks. The Pegu system does not contain any fossil remains of any solid organic substance from which the oil now included in its strata can be supposed to have originated, and on the other hand the Irrawaddy system does contain abundant fossil remains (fossil-wood) from which, at some time, hydrocarbon compounds have been removed, and these hydrocarbon compounds do not occur now in the rocks of the Irrawaddy system.

The silicified wood now found in the strata of the Irrawaddy system is interesting. It consists usually of fragments of tree trunks and branches, and the original structure of the wood is faithfully reproduced in silica. Theobald made the following suggestion for its origin[3]:—

> "The trunks of trees in question floated about till water-logged in shallow lakes, in which, on sinking, they became mineralised through the agency of springs holding silica in solution."

Dr. E. H. Pascoe has made the obsrevation that the fossil wood has the appearance of drift-wood which has been denuded of most

[3] *Mem. Geol. Surv. Ind.*, Vol. X., p. 64.

of its branches by decomposition and rough treatment in swirling waters, sinking when waterlogged and being rapidly covered by sand banks.[4] However the silicification of the wood was effected it seems that the process must have been a comparatively rapid one, since Mr. J. D. Hamilton, of the Indian Forest Service has pointed out to me that certain specimens of the fossil-wood have portions of the bark preserved in silica.

If the process had been a slow one the bark would almost certainly have disappeared from the wood by decomposition before it became silicified. Another point that does not seem to have been sufficiently emphasized is the nature of the wood. Almost all the specimens of fossil wood found in the Irrawaddy system of Burmah seem to be referable to the genus *Dipterocarpus*. Specimens of fossil wood belonging to the palms are found occasionally, but they are distinctly scarce. All these woods belong to the non-floating varieties, and they all sink in water. Therefore any theories based on the assumption that they would float are untenable. Another characteristic of the genus *Dipterocarpus* is that the trees form resinous substances on a large scale in their leaves and deposit them in their wood. In the living tissue these substances are in a liquid oily condition, while in old dead wood solid masses are deposited.[5] The wood-oil yielded by these trees is the Garjan oil of European and Indian commerce and consists of a volatile oil holding in solution a resin. Trees are tapped a few feet above the ground for four months in the year and according to Roxburgh, writing of *D. turbinatus*, "The average produce of the best trees during the season is said to be sometimes forty gallons."[6] The total amount of wood-oil present in a full grown tree, therefore must be considerable. Not only, therefore, has a vast quantity of carbonaceous matter been removed in some form or another during the silicification of the fossil-wood now found in the Irrawaddy system of Burmah, but it seems probable that at the same time a very great quantity of oil has been removed. It seems almost impossible that the carbonaceous matter could have been removed in the solid state and yet the structure of the original wood be faithfully preserved in silica, and therefore it seems that it must have been removed either in a liquid state, or a gaseous state, or both. When vegetable matter decomposes in fresh water swamps or lagoons, it becomes carbonized under the action of bacteria. Hoppe-Seyler has shown that under such conditions methane and carbon dioxide also are formed, but no higher hydrocarbons.[7] This action is stopped by brackish or salt water.

[4] *Mem. Geol. Surv. Ind.*, Vol. XL., part 1, p. 41.
[5] J. S. Gamble, *Manual of Indian Timbers*, p. 69 (1922).
[6] Watt, *Dictionary of Economic Products of India*, Vol. III., p. 164 (1890).
[7] *Zeitscher. f. physiol. Chem.*, 1886, pp. 201, 401.

Zuber has shown that under bacterial action in salt water more fatty and tar-like substances are produced.[8] During the silicification of the wood now found fossil in the Irrawaddy system of Burmah, since carbonization did not take place, it seems possible that a certain amount of fatty and tar-like substances may have been produced, since the silicification must have taken place in a silica solution and not in ordinary fresh water.

The next point of interest is, where did the silicification of the wood take place? The present extent of the Irrawaddy strata over Burmah indicates that the second main phrase of the Himalayan uplift had shallowed the arm of the sea between the Arakan Yoma Island and the Chinese mainland, but had by no means obliterated it, and most of the area must still have been covered by shallow water in which the Irrawaddy strata were laid down; and if the age of the trees is presumed to be contemporaneous with the deposition of the Irrawaddy strata, and the silicification to have been effected in the strata themselves after the fragments of wood had been entombed in them, it is difficult to see how the wood could have got into the strata in its present fragmentary state. Also the strata of the Irrawaddy system do not show any evidence of having been permeated extensively by siliceous waters, such as might be supposed to be instrumental in the replacement of wood by silica. Had such siliceous waters permeated the siliceous sands of the Irrawaddy system one would expect that in parts at least, the sandstones would have been converted into quartzites, which is not the case. The Negrais rocks, which occupy the eastern flank of the Arakan Yoma range, on the other hand, do exhibit evidence of having been extensively permeated by siliceous waters. These rocks are infiltrated, indurated, and veined with silica and chert in a most striking way, so much so that this characteristic defines the Negrais rocks. In age they are probably mostly Cretaceous, but it seems probable that they constitute a petrographical rather than a stratigraphical group of strata.[9] Now the Irrawaddy system not only consists essentially of siliceous sedimentary rocks, but its conglomerates consist almost entirely of quartz pebbles, and it seems the simplest explanation to assume that between the first and second main phases of the Himalayan uplift the newly elevated Arakan Yoma Island was subjected to an outpouring of siliceous springs (whether thermal or not it is impossible to say) which not only caused the induration and infiltration with silica of the rocks they passed through, but also deposited a certain amount of silica on the surface. After the second main phase of the uplift, much of the silica so accumulated

[8] *Zeitsch. prakt. Geol.*, 1898, p. 84.
[9] *Rec. Geol. Surv. Ind.*, Vol. XLI., part 4, p. 250–251 (1912).

would be removed by denudation and erosion to form the sands and conglomerates of the Irrawaddy system. The question then arises as to whether the silicification of the wood now found fossil incorporated in the strata of the Irrawaddy system could have taken place on the Arakan Yoma Island between the first and second main phases of the Himalayan uplift, and the author contends that not only could it have done so, but that the evidence available indicates that such was the case.

Trees belonging to the genus *Dipterocarpus* grow on the Arakan Yomas to-day up to an elevation of 2000 feet and over. Moreover they prefer a siliceous soil and consequently might be supposed to thrive during the siliceous conditions when the rocks of the Arakan Yoma Island were being saturated with silica. After the first main phase of the Himalayan uplift the newly elevated Arakan Yoma Island would naturally be subjected to active denudation and erosion, and the streams on it would not be gentle flowing streams with a gentle uniform gradient, but would be a succession of rapids and pools and possible waterfalls. They would almost certainly erode and cut into their banks at a great rate and consequently acquire trees which would fall into them. Whether any lagoons would be formed or not, it is impossible to say, but with elevation going on all the time it seems unlikely. To take the case of a single stream on the island at those times, the water almost certainly contained silica in solution, and trees belonging to the genus *Dipterocarpus*, which fell into it would sink and be retained in the pools of the river, and be subjected to the silicifying action of the siliceous water. Now it is known that such trees contain wood-oils in great quantity, and this oil being ejected from the wood during the process of silicification would, in the natural course of events, become incorporated in, and deposited together with, the Pegu sediments that were being deposited at the time, in the manner demonstrated by the author in his paper on the "Sedimentary Deposition of Oil" referred to previously. The silicified tree trunks would remain in a gelatinous or cheese like condition at the bottom of the pools. After the second main phase of the Himalayan uplift the removal of these gelatinous or cheese like silicified trees would be a comparatively simple matter since with their included water they would be of considerably lower specific gravity than the final hardened stone. Moreover gelatinous silica tends to break up into angular fragments when broken under water and thus one would expect to find the fragments of the silicified trees in just such angular fragments after transportation and deposition as one does now find the fragments of fossilized wood in the Irrawaddy system. Also one would expect to find the fragments of fossilized wood to be very much greater in size

than the other component parts of the sedimentary deposits, owing to their much lower specific gravity at the time of transportation and deposition, which is exactly what one does find in the strata of the Irrawaddy system.

It is probable that during the siliceous spring phase on the Arakan Yoma Island, new springs would continually be commencing and thus give rise to new streams which would collect more trees, and it seems that no further explanation need be sought for the origin of the fossil-wood now found in the Irrawaddy system of Burmah. Also the wood-oil that was ejected from the wood during the process of silicification would, under these circumstances, be incorporated in the Pegu sediments. It may be argued that the quantity of mineral oil now occurring in the Pegu strata is too great for this explanation to account for all of it. This may or may not be so. The quantity of fossil-wood belonging to the genus *Dipterocarpus* occurring in the Irrawaddy system must correspond to a very great quantity of original wood-oil. Also it seems possible that during the process of silicification the formation of wood-oil may have been increased. Resins (including the wood-oil of Burma) are generally the products of the degradation of the cell walls. In some species the change into resin is brought about in those cells the vitality of which has been diminished by any cause; and it is for this reason that resin is found in greatest abundance near wounds.[10] It seems quite likely therefore that during the process of silicification much of the carbonaceous matter of the original wood was converted into oils and resinuous substances, in addition to possible fatty and tar-like substances, and if so this would tend to increase enormously the amount of oily material deposited in the Pegu sediments. The only further assumption necessary is chemical change and rearrangement in the oils after they were entombed in the Pegu sediments, and this seems not only possible, but almost certain to take place under the changes in temperature and pressure the strata must have been subjected to since the time of their original deposition. The sequence of events, therefore, from the time of the first main phase of the Himalayan uplift to the time of the third and last main phase, and the history of the natural processes at work during this period, as far as they can be reconstructed from the evidence now available, point to the fact that a large quantity of oil, of the nature of wood-oil, must have been deposited in the Pegu sediments. The similar nature of all the oil now occurring as mineral oil in the Pegu strata would appear to point to the fact that it all must have been formed in one way, and that it is extremely improbable

[10] Govt. of Burma, *Manual of Forestry for Burmans, Utilisation*, Vol. II., p. 91 (1903).

that part of it represents oil which was derived from *Dipterocarpus* wood during the process of silicification, and that part of it was produced by totally different processes, from different material, at a subsequent date. The amount of hydrocarbon compounds that have been removed from the silicified wood now found fossil in the Irrawaddy system of Burmah must be much more than equivalent to the amount now occurring in the Pegu strata as mineral oil, and no further explanation of the mode of origin of the oil now found in the Pegu strata appears to be necessary. In this case the origin of the oil measures of the Pegu system of Burmah would appear to result from the combination of mountain making earth movements, a profusion of vegetation of the genus *Dipterocarpus*, and the outpouring of a great quantity of siliceous springs.

The above suggested origin of the Pegu mineral oil has one definite bearing on the distribution of the oil in Burmah. The sediment carried by the Arakan Yoma Island streams into the arm of the sea between the island and the Chinese mainland would become sorted out as it subsided through the still waters of the arm of the sea. The coarser material would settle first and be deposited close to the island while the impalpable mud and clay would be carried far out into the sea before it settled. If oil was incorporated in some of the impalpable mud, such oil bearing mud would be naturally of lower specific gravity as a whole than similar mud in which oil was not incorporated, and therefore one would expect oil bearing mud to be carried further out to sea than similar mud that was not oil bearing. As streams would also be coming into the arm of the sea from the Chinese mainland one would expect the greatest accumulation of oil bearing mud to take place about the middle of the arm of the sea. It is significant, in view of this reasoning, to find that practically speaking very nearly all the mineral oil produced from Burmah has come from the Yenangyaung, Singu, and Yenangyat fields, which occupy approximately a central position of the area originally occupied by the arm of the sea between the Arakan Yoma Island and the old Chinese mainland, and that the production from all the other known oil producing localities not so centrally situated amounts to only a small percentage of the oil produced from Burmah to date.

The Prevention of Explosions in Air Receivers.*

WILLIAM F. PARISH AND WILLIAM B. SMITH WHALEY.

Explosions in receivers and air lines of compressed air plants are of such frequent occurrence that the technical press no longer recognises their news value and descriptions of such explosions, when offered to magazines specialising on power and compressed air, are rarely printed unless they present some novel feature.

It is generally conceded that air receiver and line explosions are caused by explosive mixtures due to air and, primarily, the lubricating oil, but no research is had to date that suggests a positive remedy. It is suggested that less oil be used; obviously too little lubricant may lead to disastrous results through overheating of the parts and causing mechanical damage to the bearing surfaces without improving the situation in regard to the forming of explosive vapors. True, the reduction in oil feed will increase the time necessary for the formation of mixtures that cause the explosions but they will be formed eventually and cause trouble. Explosions formerly were followed by a demand for a higher flash point oil, until it was found that the use of such oils did not reduce the trouble. In fact explosions occur with the use of both low flash and high flash oils. Also explosions are not limited, by any means, to compressors where only the lowest grade and least expensive oils are used but they occur wherever oils of any kind are used. This makes it clear that the trouble cannot be remedied or prevented through a control of the character of the lubricant.

It is impossible to operate the compressors without lubrication of some sort.

When the animal or vegetable oils were in use, which was at the time compressors were first introduced on a commercial scale, explosions were common. These fixed oils, as they are called, will liberate free fatty acids when used under high heat conditions and gums are formed as a consequence. These gums are very detrimental to the condition of bearing surfaces and seriously effect lubrication. While it is true that the fixed oils will not liberate volatile vapors or explosive gases the same as the mineral

* Read before the Metropolitan Section, Petroleum Division, American Society Mechanical Engineers, New York City, April 9, 1925.

oils, explosions do occur under conditions where there is an accumulation of these easily oxidised and highly inflammable gums and oils.

With all of the mineral oils, from the lightest to the heaviest, some decomposition takes place under the heat and pressure in the air compressor cylinder and valve chests. The proof of this is in the carbon residue which is always left after oil has been decomposed and the lighter and more volatile products have been freed. That carbon residues are formed we have sufficient evidence in the reports of the examinations of deposits taken from air compressors, whether before or after explosions. These deposits, when examined, have always been found to be composed of free oil and carbonised oil in almost equal proportions. There is generally about ten per cent. of foreign matter such as iron and other metal from the wear of the compressor parts, with some rust. Dirt and particles of raw material from about the plant are also found, such as coal dust, cement, fibres and vegetable material. The entire amount of deposit is held together by a binder formed from the sticky part of the burned lubricant. These residue deposits, of themselves, sometimes cause air line failure and they can materially aid in the formation of the more volatile oil vapors out of the heavier vapors by their action as catalysers. It has been shown that deposits will materially lower the ignition temperature of vapors in an air line. When an air line starts to fill up with this deposit, which is generally at some point of natural obstruction, the restricted passage forms a trap and allows the collection of the vapors and oil. When conditions are right an explosion or a series of explosions of non-violent nature then take place which can be dissipated along the lines and cause no material damage. The heat of each explosion, however, bakes the carbon residue formation hard and finally overheats the pipe so that it eventually ruptures. In such a case the heating and baking of the carbon is the result of the explosion and not its cause. It has hitherto been thought that these carbon deposits ignited by themselves, or heated by the friction of the air to a point where they would ignite the oil and gas vapours. There is another and more logical explanation which will be presented shortly.

The visible evidence of oil decomposition that is present in these carbon residue deposits proves the existence of a series of highly explosive gases and volatile vapors that have been liberated during the decomposition or cracking of the lubricant. These vapors can, in fact be recondensed into the familiar petroleum products, benzine, gasoline and kerosene. Some of the gas is so light that it cannot be easily condensed. All vapors and gases

released by the decomposition of the lubricant are highly volatile and explosive when mixed with the proper proportion of air. In all air compressors the lubricating oil, of whatever nature and however fed, is undoubtedly finely divided and atomised at the time it leaves the air cylinder. The heat conditions are such as to thin any oil and the swift action of the air, the pressures and heats of compression together with the working of the pistons and valves, will not only thoroughly atomize the oil, however heavy, but will decompose certain parts of it. When this action takes place there is liberated into the air passage a small amount of free oil in a highly atomised state, so fine that certain portions of it will carry along with the air to the ends of the air lines and there help to lubricate or to gum up the air tools. There is also liberated a slight amount of burned oil in the form of carbon that is entrained in the air, later to be deposited in the valve chest and along the line. The gases and vapors from the oil decomposition are also present. Some of these gases can be detected as the air leaves the tools. These vapors when mixed with the proper proportion of air can, of course, be ignited by direct flame or increased heat due to excessive pressure. When this results in an explosion the cause is not mysterious.

All of the various forms of hydrocarbon suggested above are mostly trapped within the air system to an amount that can be generated from the total weight of lubricant used. The total amount of vapour and gas is so small, as compared to the total amount of air handled, that it would present no problem if it did not accumulate. Whenever a space is left in the air system for these vapours to collect, and especially where cooling takes place, these vapours and gases will associate together in strata, the heaviest will settle and the lightest will rise and pass off in circulation whenever possible. A highly explosive and critical area is therefore present in every unscavenged static receiver or tank when air and combined combustible vapours and gases are present as is the case in air compressor receivers. This critical area exists at some point between the tank bottom, where the heavier parts of the atomised oil will settle out, and the top strata, which contains the most volatile gases. Wherever the mixture of air and volatile vapour is in a critical condition and is in contact with metal the slightest external shock may cause detonation. A critical mixture is always unstable and does not depend upon pressure and temperature for its action, and might be detonated at atmospheric conditions through molecular friction alone. After detonation this mixture will burn smokeless and with white heat, and as a consequence both the temperature and pressure rises as a result of the action, and not as the cause.

Should the area of critical mixture lie in the centre of the tank surrounded by free air it will be safely cushioned. Should the tank contain a sufficient amount of combustible vapours, lying in strata as suggested, ignition of the unstable and critical mixture can take place, and due to the over-richness of the adjoining lower strata and over-leanness of the adjoining upper strata the action may not go through the entire contents of the tank and the increase in pressure will be within the limits of the safety valve. If the conditions are such that detonation of the critical mixture will fire the entire series of strata, the result will necessarily be a violent explosion, due to heat and pressure being generated in excess of the capacity of the safety valve.

There are, therefore, various degrees of explosions possible as a result of the accumulation of these series of hydrocarbon vapours and gases. Those explosions that take place without damage are generally considered by plant men as being automatic signals that it is time to clean out the oil and water accumulations in the receiver. It is quite possible that these slight explosions can even take place in the receiver, and especially along the air lines where traps have been formed, without the fact being noted at the time. Whenever this action has taken place the result has been the formation of a quantity of CO or CO_2 gas, and it is this gas that has caused so many deaths in mines where compressed air was being used for tools and machines. Invariably, when an air receiver explodes at a mine, men are gassed in the underworkings. Deaths have been caused under these conditions even when the receivers did not suffer rupture

Safety valves, as such, come into action after the explosion takes place. They do not prevent the formation of volatile vapours and gas that causes the explosion. When the amount of vapour is slight, or conditions are not just right for an extensive explosion the usual safety valve will release the pressure and thereby prevent the building up of heat which will bring the heavier mixtures into action. Whenever explosions have taken place wrecking the air system and the plant, pressures in excess of 750 pounds per square inch have been indicated by damage done, and by concave heads of tanks being reversed. When conditions are just right for a violent explosion any number of safety valves will not prevent it. These valves prevent some explosions, but as they cannot and do not prevent all explosions they must be considered only a partial remedy

In seeking a remedy for receiver explosions we are faced with certain obvious facts, some of which point to the solution. We cannot get along without lubrication. If we could lubricate with material that did not contain hydrocarbons, alcohols, glycerines, or fatty oils these explosions would not take place. With the present mineral lubricants we can reduce the feed sufficiently to

prevent conditions which might result in an early explosion, and we might then cause damage to the machines by depriving them of needed lubrication. Also we cannot guarantee that the compressors and tanks shall be free from shocks and excessive temperature rises from which ignition might take place. It is, and has been, obvious for years, that these explosions will not occur if air and oil vapours are prevented from accumulating and forming combustible gases. The remedy lies in introducing preventative measures. Pockets and traps can be guarded against in the air lines. As regards the receiver, we can introduce means for constantly scavenging the tank and thus can prevent the accumulation of oil vapour and vapour mixtures, thereby prevent explosions.

This receiver scavenging method was developed as the direct result of an explosion. When applied to air receivers where explosive mixtures should form it has prevented their formation over a period of seven years. The details are of interest in this connection. While working on one of the experimental engines of a new cycle, an explosion took place in the 12 in. by 24 in. air receiver for 200 pound air. Force was generated that was sufficient to blow out a fitting in the line at the compressor cylinder. This fitting struck a gentleman standing twenty feet from the engine in the neck with the force of a bullet, severely injuring him. The receiver was examined and found about one-fifth full of oil which had apparently reformed from the oil vapours thrown off by the compressor piston. The receiver had been subjected to flame and was very hot after the fitting had blown off, its condition not having been noted immediately before the explosion. The receiver and the oil in it was held for further experimentation and a new fitting was made very much stronger than the first. All parts of the system were strengthened and a pop safety valve was put on the line. The engine was then started and within two hours the mixture again carburetted in the receiver, the explosion being of such force as to greatly increase the temperature of the receiver; the safety valve in this instance relieved the pressure before damage was done. The oil in the receiver was not burned and the temperature rise did not take place before the safety valve blew off. The gas and combustible vapours did not come from the oil that had already collected in the receiver, because in this case a temperature in excess of 500° F. would have to be maintained for a long enough period to heat the entire body of the oil to that degree before ignitible vapours would have been produced. It is questionable if such conditions could obtain. In this case temperature was not noted until after the explosion and then much less than would have been necessary to secure vapours from even a small amount of the kind of oil used on the engine.

A scavenging valve was then made and placed on the air receiver. With this valve the air enters and leaves the receiver through the same opening. The mechanism of the valve allows the pressure to open a passage for the compressed air to the top of the tank. The outlet opening has fitted to it a length of pipe that goes to within a few millimeters of the bottom of the tank. Any air flowing from the pump or compressor to the air system, therefore, has to pass from the top of the tank entirely to the bottom before it can leave. This effectually sweeps all vapours and gases from the receiver and keeps it full of pure fresh air with only a minute amount of oil and vapours that, however, do not have a chance to collect and stratify.

These scavenging valves have been fitted to the tanks on all experimental engines that have been built during the development of this new cycle. The air receivers of these engines have never carburetted. During the testing of Experimental Engine Number Eight of 400 B.H.P., which ran for over 4,000 hours, there was no carburetion in any of the receivers, all of them being fitted with the new scavenging valves.

This scavenging valve is an integral part of the tanks of a new gas and oil engine which will shortly be offered to the public. The value of such a valve is so obvious that it will be offered for general use on the receivers and tanks of other engines. It is thought that a development that has to do with the safety of life and property, should have wider application than could be given it by confining its use exclusively to the inventor's own type of engine.

It is hoped that the suggestions contained in this paper will make clear the reasons for the many air compressor explosions that have occurred in the past, the origin of which were thought to be mysterious. It is also hoped by the authors that the solution to the problem of explosions in air receivers determined by a long series of tests will appeal to all engineers.

Bringing Wells into Production.*

By A. Frank Dabell, M.I.Mech.E.

Those responsible for the commercial success in oilfield operations must view with concern to-day the expense of winning oil by the bailing method, with its demand for continuous power and renewal of ropes, belting, etc.

Violent eruption is occasionally more profitable, but not invariably so, by reason of its attendant risks of fire, destroyed casing and fishing operations.

Commercial success results from the steady enduring flowing well, and it is the purpose of this article to study the conditions under which such occurs, with a view to reproduction.

Primarily it is a fallacy to believe that more skill is required to drill a well than to bring it into the profitable stage. In fact, the contrary is the case, for to obtain a drilled well the engineer may hand the casing programme to a skilled boremaster, who, left to himself, will often drill a well with an efficiency of 100 per cent. in every factor contributing to the desired result.

This state of perfection is never attained in producing.

Latent Energy.—It is probable that there is or was in every oilfield sufficient latent energy to lift the entire content of its sands to the surface, therefore the control and regulation of release of such power governs the end attained.

A feature of this regulation is the area of the orifice of discharge; otherwise the power is expended without the useful effect of lifting oil.

Well Diameter.—The diameter of wells in developed fields in which steady continuous flow has been obtained shows that this has either been reduced to the minimum in which drilling is practicable or that the area of discharge at the base of the working column has been reduced fortuitously by obstruction or loss of diameter.

In other cases it has been seen that wells, having no tendency to flow through the working column, have done so when the column, having passed the face of the sand, offered a reduced area of discharge by the annulus formed between the exterior of the working column and the interior of the preceding columns.

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* This also appeared in the *Moniteur du Pétrole Roumain*, June 1, 1925, and is translated by the author.

Again, the desired result has been attained by the delivery through the water channel of water flush tools and stem suspended in the producing sand.

Further evidence to the same effect lies in the fact of placing perforated casing over the face of the producing sands. Whilst the nominal purpose of this practice may be to prevent caving, in effect it restrains flow.

The most profitable well coming under the writer's experience flowed continuously for sixteen months through 8-inch casing with detached tools in the bottom.

Eventually these tools were found standing in their original position, considerably worn by the sand, in a perfectly clean hole. Later other new wells sunk within one hundred metres radius failed to yield sufficient oil to supply the power needed for their development.

Flow.—From the foregoing it is to be deduced that flow is dependent upon the area of the orifice of discharge, and varies with the pressure or quantity of gas released.

Restriction of flow, however, when practised by means of control valves or choke at the surface, results in arrest in a short period, by collection of sand in the casing.

As this sand is found in the form of a compact plug it is to be assumed that during the period of flow it was entering the well, but that the liquid supporting it lacked sufficient velocity to bring it to the surface, with the result that, becoming overladen, accumulating deposition sealed the source.

Release of Sand.—Assuming that it is necessary to give release to sand, continuous flow demands that control be practised at the point at which oil enters the well rather than at the surface, in order that increasing velocity resulting from the expanding nature of the gas, following the law of Boyle, may lead to expulsion of the sand after entry, rather than its accumulation in the well.

Porosity.—Valuable contributions upon the subject under consideration are published by Mr. Harry Pennington in a paper entitled "Migration of Sand,"* in which he declares that in the United States "when all sand be shut out from a well then the oil also is shut out."

In another paper, "Theoretical Mechanics of Flowing Wells,"† the same author states that "the influence zone of wells is proportional to the freedom of flow through the porous container-sand."

"Flow is restricted through the pore spaces by capillarity and friction proportional to the degree of porosity of the sand."

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* *The Oil Weekly*, October, 1923.
† *The Oil Weekly*, December, 1924.

"Whilst pressure in a sand, like all fluid and gas pressure, is equal in all directions, flow is towards the free portion whatever the direction."

Area of Drainage.—That sand is composed of varying sized particles may be proved by the examination of samples cleaned from wells in their initial producing stage, which will be found to be of much finer texture than that of the rock encountered in drilling, or even of that drawn in by swabbing in perforated casing column directly in contact with the sand, etc.

It follows, therefore, that where it is possible to allow the liquid in its movement to bring forward and discharge through the well the finer sand grains, increased porosity is obtained, and the more distant the point from which this operates, the greater the area of drainage is embraced by any particular well.

Conversely, in the case of uncontrolled violent eruption when a large quantity of sand in motion toward the well is suddenly arrested, the state at the point of entry to the well must be the reverse of that desired, for the probability is that, following its sudden arrest, the local degree of density must be greater than that of its original state, and unless eruption be resumed at a later date a condition of decreased rather than increased porosity remains.

The writer has experience of such in wells which, having commenced violent discharge of oil and sand, were immediately closed in to allow for storage preparations, but when reopened later entirely failed to yield again, and also in unskilfully bailed wells, where the descending bailer has tamped collected sand into a compact mass and sealed off the point of oil ingress.

Bailing.—In the principal producing fields of Russia, where it is generally accepted that without release of sand oil will not follow, the influence of sand movement upon oil output in bailing wells may best be studied.

In the Baku fields oil is obtained from intensely worked friable sand rock, generally with some water present, comparatively little gas and flowing conditions rarely encountered.

Bailing supervision is by skilled men who, by regulating the speed of bailing, diameters of bailers and maintenance of the liquid at determined levels, take from the well the exact quantity of sand entering, prevent emulsification and at times hold water in check by the maintenance of a head of oil above that of the static water level.

Bearing upon the question at issue, it is to be noted that immediately sand enters the well faster than it can be removed, action is taken to check it. This may be by reduction of bailer diameter to reduce its piston effect, or reduction of bailing speed through the

liquid, etc., but primarily whilst sand may enter it must not be allowed to collect in the well.

The quantity of sand thus removed may be judged by the fact that derricks are constantly lifted to maintain a position above that of the accumulating sand, and when this becomes unnecessary declining output follows.

It is unfortunate that those who casually study this matter should deduce that productivity is dependent upon the ejection or removal of a given volume of sand, as though some sort of cavern were formed thereby, for this is responsible for transforming the sand body into a semi-liquid form of low porosity, which cannot be controlled, and is responsible for release of clay, deflected casing, and great loss of time if drilling is resumed.

The truly-developed well in sand rock, when its flowing and bailing period is past and the yield of sand ceases, should retain in form the exposed face originally drilled. It is the failure to attain this result that often precludes well pumping.

A true appreciation of this point governs the whole question of sand movement.

The well previously referred to presented this feature, as proved by the fact that after sixteen months' flow the tools were found in a central upright position, below the casing shoe, and with no cavity around.

Induced Flow.—It follows that the total output and longevity of a well are dependent upon its area of drainage defined by the relative degree of porosity of the oil-bearing sand encircling it. Further, that increased porosity is obtained by the removal of the finer sand grains and silt by oil in emigration, to obtain which a steady flow is necessary.

Steady flow under varying gas pressure is to-day being obtained in several fields by the flow-line method, which in effect reduces the orifice of discharge at the productive depth.

Tubes of an average of 75 mm. diameter are lowered to the depth of the producing sand with a packer making hermetic contact between the tubing and casing some few metres above.

The form of the packer is immaterial providing it prevents the gas rising in the casing and compels it to seek outlet by way of the tubing.

So far as the diameter of the tubing is concerned this must be dependent upon the gas available, and in wells giving sand it is better to have the tubes sufficiently large to permit of swabbing to induce flow should stoppage occur.

A diameter of 3 inches would satisfy these conditions and progressive descending reduction could be practised in the lower sections when necessity demands.

Packer.—Unless the packer be at the bottom of the well a disturbing element prevails by reason of the pressure building up in the annular space between the flow pipe and casing and exerting a back pressure upon the face of the oil sand.

Under these conditions whilst sufficient latent power is available to maintain the flow of a comparatively light mixture of oil and gas vapour in the flow line, the dense volume of liquid standing in the annular space may bring about a state of stagnation.

Location of Choke.—The placing of a choke in the bottom of the well is now being tried in the United States, but no definite pronouncement in its favour is yet forthcoming, though this may be due to the technical difficulty of its application.

The writer has no hesitation in declaring himself in favour of the principle involved, and in recommending its practice by the placing of an obstruction at the foot of a potential flowing well.

Mr. T. E. Swigart, in an address recently delivered to the American Institute of Mining and Metallurgical Engineers upon the Efficiency of Flowing Wells, declared that :—

> "Laboratory experiments, together with field observation, have shown that oil and gas move much faster through the open textured porous streaks in the oil-bearing formation than through the tighter close-grained parts of the sand. That while much larger quantities of oil have been extracted from wells with a 4½-inch flow pipe in a short time, their decline is much more rapid and their efficiency much less than wells with 3-inch tubing.
>
> "One advantage of tubing a deep well is that sand and other debris is removed as fast as it enters the hole, and the hole is automatically kept clean."

Plug.—It is obvious that with the use of the flow-line system, declining pressure will eventually compel reversion to less economical methods of production, but whether such be swabbing, bailing or pumping, the sand migration factor remains paramount, for when the finer-grained particles in the nature of silt drawn from the increasing zone of influence of a well, be deposited around the well itself, an impervious barrier is formed, and the result is the antithesis of that which the writer urges should obtain.

When this silt enters the well forming "a few metres of plug," and is made compact by a continuously descending bailer, technical and commercial disaster accrue.

As oil should have free ingress to the well, any effort which draws sand into the bore at a faster rate than that at which it can be removed is detrimental to oil recovery.

The most common practice tending to this effect is: bailing from the surface of the liquid, the use of large diameter bailers tending to act as pistons in the casing, and sometimes swabbing in the early stages.

Summary.

Summarising the foregoing:—

Continuous flow is dependent upon restrained release of oil at its entry into the well, and an increasing facility for escape thereafter.

Prolongation of flow and ultimate yield are dependent upon the area of drainage embraced.

Area of drainage embraced is dependent upon obtaining a reduction of rock density by steady movement of liquid carrying all released sand to the surface.

Rate of release of sand should be dependent upon that quantity which the oil can carry.

The diameter of pipe through which flow is to be taken is dependent upon the character of gas encountered and is not necessarily that of the diameter of the final casing column—which results from the exigencies of drilling.

The application of these principles for gaining efficient production demands that, when bringing a well into production, whether by flow pipe, swab line, air lift, pump or bailer, oil be captured at its point of inlet into the well.

STUDENTS' SECTION, LONDON BRANCH.

A meeting of the London Branch of the Students' Section was held at Aldine House, Bedford Street, London, W.C. 2, on January 20th, 1925, and a précis of the paper read follows :—

Organic Theories of Oil Origin.

By E. CLARK (STUDENT).

A CLEAR understanding of the origin of petroleum would give greater insight into its mode of occurrence and simplify many geological problems.

Organic theories state that oil originated from animal and/or vegetable matter, deposited contemporaneously with sediments.

Points to be settled are : (i.) The nature of the original organic material. Opinion differs chiefly as to whether the material is animal or vegetable, terrestrial or marine ; and (ii.) The mode of accumulation of the original material and its chemical change to petroleum, with especial reference to the environment.

The whole problem is of such magnitude as to demand concerted effort for its solution, rather than the individuality which has characterised existing theories.

The evidence in favour of the organic theories (as opposed to inorganic) may be summarised as follows : (*a*) Petroleum in considerable quantity is everywhere associated with sedimentary rocks, and there can be little doubt that it originated from the organic contents of sediments. Igneous rocks are rarely met with in oilfields, and, where they do occur, are of structural significance only—*i.e.*, by their agency the associated sediments have been flexed, metamorphosed or dammed to form reservoirs suitable for oil accumulation—*e.g.*, Mexican fields. If petroleum were of inorganic origin, it would be reasonable to expect its occurrence in reservoir rocks of all ages, so long as structure and lithology were suitable. Actually, however, the reverse is the case, for petroleum in quantity seems to characterise certain geologic strata over wide areas—*e.g.*, Carboniferous U.S.A. ; Miocene Europe and the Tertiary generally throughout the world. This suggests that during certain periods of geologic time conditions of sedimentation favoured preservation of organic matter, which has become chemically modified to form petroleum ; (*b*) It is chemically possible to obtain

oil from most types of organic matter deposited with sediments; further, geological conditions, as far as they can be interpreted, would be generally favourable for the necessary chemical reactions to occur. The quantity of organic matter deposited was almost certainly more than sufficient to account for the vast supplies of petroleum found.

The various theories have developed along two main lines of thought, one postulating the formation of petroleum from animal or vegetable matter deposited under marine conditions, the other invoking terrestrial vegetation and deltaic or gulf conditions.

The chief difficulties attending investigation are due to the fact that petroleum retains no fossil evidence of its origin, and further, being a liquid, it is liable to underground migration from the place of origin.

The natural laws governing the migration and accumulation of petroleum are as yet imperfectly understood; and until they are this difficulty will impede investigation of its origin.

Marine Theory.—The majority of oil deposits of the world are located in marine strata or are related to marine rocks by migration. Oil and gas commonly occurs in lenses of arenaceous material within shales or clays and is almost invariably associated with brine.

The conditions of sand deposition are normally oxidising and therefore unfavourable to the preservation of organic matter; ample evidence indicates argillaceous and calcareous sediments as the usual mother-rocks.

The presence in the shales and clays of easily oxidised minerals indicates reducing conditions operative during some phase of deposition; moreover, these rocks frequently contain protozoa, diatoms or marine algæ. Such prolific and short-lived organisms would favour rapid accumulation of organic matter.

It is noteworthy that the oxygen content of water is a function of the stagnancy as well as the depth.

Bosworth has estimated that "the quantity of carbon required to produce all the oil yet taken out of the Mid-Continent fields would be only 0·00023 per cent. of the whole mass of sediments." Although this figure is only approximate on account of the assumptions involved, it serves to show that the organic content necessary for the formation of the petroleum is not abnormally large. It would appear that conditions essential to preservation of that organic content within the sediments are of more importance.

Chemical evidence is conclusive on one point—that the nitrogenous content of the organic matter must be eliminated prior to the formation of petroleum. The conclusion arrived at from a discussion of Engler's stages is that though the latter are theo-

retical rather than established facts, they give a plausible solution to a very difficult problem. This theory implies a process similar to destructive distillation by which the principal chemical changes are brought about. The only apparent cause of increased temperature is the blanketing effect of overlying sediments, which in favourable circumstances might give an increase of 150° C. The resultant temperature being insufficient for destructive distillation suggests that the geologic time factor might compensate, but a certain initial temperature must exist before the chemical reaction will occur.

Characteristic distillation curves for British cannel and oilshale indicate an initial temperature of approximately 300° C. necessary before distillation can commence. Such a fact explains the existence of these rocks unchanged to the present day; possibly the mother-rock of oil possessed a lower initial distillation temperature. Since the volume of the products of the reaction would be much greater than initially, increased pressure would favour the reverse reaction (with decrease in volume) in a closed system.

The bacteriological theory suggests the formation of oil due to bacterial action on the organic matter, during and after sedimentation. The process of compaction is then employed to explain the expression of brine, oil and gas from the argillaceous sediments into the porous arenaceous reservoirs, where separation takes place, due to gravity, capillarity and other factors. Bacteria are known to cause fermentation and to deoxidise sulphates to sulphides in sediments forming at the present day. According to this theory certain bacteria would cause removal of nitrogenous substances from deposited organic matter, and, in complete or partial absence of oxygen, other types of aerobic bacteria would consume oxygen from the fats, yielding hydrocarbons.

Such evidence as is available from marine deposition indicates an adequate inclusion of organic matter, and even the presence of petroleum-like hydrocarbons. The almost universal association of salt and brines with petroleum finds a ready explanation as being due to the inclusion of sea-water in the sediments during deposition. If a general freshwater or deltaic origin of oil is assumed, it is not clear why there should have been selective migration into rocks of marine origin.

Geologic evidence indicates that many limestone oils are indigenous to the rocks in which they are found.

In the Californian and Trinidad fields there is strong evidence that oil originated from micro-organisms in strata deposited under marine conditions.

To sum up, it is evident that a very strong case can be made for the origination of petroleum from organic matter under marine

conditions, in spite of the fact that our knowledge of the special conditions of sedimentation is still incomplete.

Terrestrial Origin.—More is known of the deposition of terrestrial vegetable matter in shallow water environments—*e.g.*, in deltas and gulfs. Incalculable quantities of carbonaceous matter have been preserved in the form of coal, indicating that during past geological periods, as now, there was an abundant supply of vegetation, together with conditions favourable for its preservation and conversion into hydrocarbons. It has been suggested that the formation of petroleum developed along the following lines :—Prolific vegetation of warm deltaic regions became entombed within the accumulating silts and muds. Subsequently, increased pressure and temperature, due to superincumbent deposits, induced chemical changes analogous to destructive distillation, producing either petroleum or carbonaceous substances, according to the physical conditions obtaining. It seems difficult to explain why the general types of hydrocarbons are different in each case and why most coal deposits occur in deep-seated Palæozoic rocks, as contrasted with Tertiary oilfields. The absence of appreciable amounts of organic nitrogen compounds from petroleum is noteworthy.

Decaying vegetation does undoubtedly decompose to yield hydrocarbons such as methane and ethane, present in marsh gas and in natural gas in large proportions. This is a strong, positive argument in favour of the vegetation origin, though it is not free from adverse criticism.

The hydrocarbons of crude oils are chain or ring compounds of high molecular weight and their formation from such compounds as methane would involve increase in the size and complication of the molecules. Normally, however, heavy hydrocarbons tend to break down into simpler forms, as in "cracking" operations. The presence of catalysts, such as nickel, which forms rather a large percentage of most petroleum ash, might modify the chemical reactions, but it is probable that such catalysts would be poisoned (*e.g.*, by sulphur compounds) before they could operate appreciably.

The swampy conditions under which methane is now formed are similar to those under which coals and lignites were formed, and it is considered that evolution of gaseous hydrocarbons is a stage in the formation of these carbonaceous solids. If petroleum had been formed from the same raw material as coal and under similar conditions, an intimate association, allowing for migration of the fluids, might be expected. The geological evidence in some fields, notably those of Burma, Assam and the East Indies indicates such an association of coal and oil.

In India the petroliferous series are Tertiary sediments, deposited in three great gulfs. The oil occurs towards the deeper portions

of the gulfs and coals and lignites are characteristic of the coastal areas.

The lateral variation of coal to oil probably indicates a variation in the conditions of sedimentation and therefore constitutes a normal case of lateral variation of facies (unless, of course, the horizontal distances are very small). In considering this question, however, it should be noted that disconformity, or any evidence of earth movement or time-lapse between deposition of the petroliferous and carbonaceous series, renders doubtful the assumption of similar original environments. There is a strong unconformity between the coal and oil series of the Appalachian fields, for instance.

Although the geological association of coal and oil is evident in some important fields, it is not so universal as to form, in itself, a conclusive argument for the similar origin of both.

Summarising, it is evident that, although important deposits of petroleum may have originated from terrestrial vegetation under deltaic or lacustrine conditions in certain fields, such an origin is generally improbable. No common theory is sufficient to explain the origin of all petroleum deposits, but each deposit must be judged on its own merits. Such a conclusion is inevitable when the wide possibilities of variation in sedimentary conditions are considered; further, it serves to explain the chemical diversity of various oils.

The factors determining the ultimate composition of crude petroleum may be classified as follows:—

(i.) The nature of the parent substance, its environment and deposition.

(ii.) The types of chemical reactions which transform the organic matter to petroleum hydrocarbons.

(iii.) The modifications caused by contact of the petroleum with rocks and underground waters during migration.

Brines.—Salt water is almost invariably associated with petroleum, and may be expected to yield valuable confirmatory evidence of the origin, especially as regards environment. The evidence of brines, however, is rendered difficult of interpretation by reason of subsequent chemical and physical alterations to which these solutions are liable. Moreover, since brines are of little commercial value, their nature and distribution have not been fully studied.

Available evidence is not inconsistent with a sea-water origin of the brines which are so closely related with petroleum.

Although rather variable in certain of the less important constituents, deep oilfield brines are too generally uniform in composition to have been the result of indiscriminate leaching of rocks by meteoric waters.

Finally, the underground occurrence of petroleum is determined by variable influences, of which the genesis of the oil is the most fundamental, and the geologist is concerned with gauging the extent and effect of these natural phenomena. Evidence of structure, lithology, surface shows, etc. are all employed in estimating the probable origin, migration and accumulation of the oil with a view to the proper selection of well-sites. A knowledge of the origin of petroleum necessarily constitutes the basis of attack on problems of Migration and Accumulation, matters of primary importance to the oil industry. As a generalisation, practically any type of organic material—diatoms, algae, foraminifera, vegetation, etc.—which became entombed within a sediment could eventually form petroleum, given the necessary physical and chemical conditions.

In this respect many of the theories might be conceived as portions of a more general theory. The more important requirement would seem to be that sedimentation conditions should be of a reducing character, with possibly bacterial intervention.

Probably these conditions had been realised fairly frequently during geologic time, and *since* the odds were very much against petroleum being preserved for long, it seemed remarkable that such a prodigious quantity had remained. Further, this quantity, representing a small fraction of the total amount, made oil formation seem a more normal phase of sedimentation than ever.

In studying this subject, while admiring the ingenuity of the theories suggested, one cannot overlook the fact that much of the evidence on which they rest involves a degree of uncertainty.

The relative value of evidence is controversial, and though organic theories are undoubtedly true as a generalisation, subsequent research may necessitate minor readjustments in ideas.

The main avenues of research would seem to be :—

(i.) Physiographical, involving systematic scientific investigation of deposits now forming, and particularly those of argillaceous, impure calcareous, marine types and lagoon and deltaic fresh or brackish water types.

(ii.) Geological, involving extension and possibly revision of present knowledge, as a result of further oilfield development.

(iii.) Chemical; here the problems would probably be outlined as a result of evidence from (i.) and (ii.).

It is evident that a problem of this magnitude, involving several distinct sciences, can only be satisfactorily overcome by the closest collaboration of all investigators.

For the loan of slides and for invaluable suggestions the author is indebted to Prof. V. C. Illing and to Mr. H. B. Milner.

A discussion followed in which Messrs. C. A. Sansom, D. P. Rees, H. R. Lovely, J. O. Tanner, H. S. Garlick, Prof. V. C. Illing, T. Dewhurst and H. B. Milner participated.

STUDENTS' SECTION, LONDON BRANCH.

A meeting of the London Branch of the Students' Section took place at Aldine House, Bedford Street, London, W.C. 2, on March 24, 1925, the following being an extract of the paper read :—

Petroleum Indications.

By H. R. Lovely (Student).

The term "Petroleum Indications" is not applied only to the occurrence of bitumen at the earth's surface. Indications may be classified as follows :—

(*a*) Actual occurrence of oil or bitumen as a seepage or impregnation.
(*b*) Occurrence of substances commonly associated with petroleum such as salt, oil-shale, etc.
(*c*) Peculiar rock types due to alteration in texture and colour, consequent upon impregnations.
(*d*) Miscellaneous indications.

These possibilities of a seepage or small quantity of oil at the surface are as follows :—

1. The oil may be the remnants of what before denudation occurred was a large reservoir, but which, through gradual loss, is now nearly empty.
2. The oil may be coming from a small lense.
3. The oil may be just exuding from a saturated clay or shale, in which it was formed, but owing to the lack of a porous reservoir, it is still dispersed in the form of minute globules.
4. The oil is coming from a large existing reservoir underneath.

In assessing the value of a seepage, therefore, an intimate knowledge of the stratigraphy and structure of the area is necessary.

Gaseous Indications.—The simplest form of a gas seepage is a series of bubbles of CH_4 coming up through the ground. H_2S may be associated with natural gas and will only too clearly make

its presence felt, thus calling attention to a possibility of a gas show.

Very often the gas bubbles up through a pool of water, but if the water is at all stagnant, methane will be found in decaying vegetation and from time to time will escape in bubbles, thus giving the appearance of a natural gas escape, consequently the bubbles must be watched. If they come from a particular spot and are continuous, possibly agitating the surrounding water violently, then it is fairly certain that they are natural gas. Gas coming up thus may give a film of oil on the surface of the water, which is additional evidence.

Possibly the most familiar phenomenon that a free gas seepage gives rise to is the so-called mud volcano. Mud volcanoes may be divided into two types—(1) composite type and (2) cone type. Composite mud volcanoes often cover a large area of ground, and are frequently associated with faults, and instead of one sharp, high cone a broad flat mound is seen. The more or less flat surface of the volcano may be dotted about with little volcanoes.

Another phenomenon supposed to be associated with gas seepages is the so-called "paraffin dirt" which has been found in various parts of the Gulf Coast oilfields of North America. The term is applied to clay soils having a peculiar texture, which has been described in various ways by different investigators. Apparently it is "rubbery" or "curdy," especially in compression. When dry it may acquire a horny consistency; when moist it varies in colour from dark brown (due to much organic matter) to a grey (more inorganic matter), while it has an odour usually associated with bogs and swamps.

Liquid indications are far more plentiful than the gaseous variety, possibly because they can be seen so much more easily, and by far the most important liquid indication is the free seepage. Seepages of liquid oil should be carefully examined and their structural position considered before any conclusion can be drawn as to the types of oil and the quantity remaining for use.

Solid Indications.—We can divide the solid indications into

1. Residual bitumen.

2. Bituminous rocks, such as the tar sands of Athabasca.

Associated Bodies.—The most important of the materials associated with oil is salt. Although not a universal indication, the presence of salt is always worth investigating.

Salt Waters.—If a salt water spring is found issuing at the outcrop of a sand, it is a bad indication for that particular sand; but oil may still be present in neighbouring sands.

Coal.—The value of coal as an indication of petroleum must necessarily be determined by the theory of origin of oil held by every separate person.

Oil-shales may be favourable indications of petroleum. The petroliferous series in the Kansas-Oklahoma fields always have oil-shales present in them, while it has been suggested that oil-shales gave rise to some of the Gilsonite veins in Utah.

Rock Types and their Alteration on Impregnation.—There are certain types of rocks which are met with in most oil-fields. Petroliferous series are generally argillaceous or calcareous, usually the former. This series will also always contain a porous rock in which the oil can accumulate.

Oil is never actually found in igneous rocks, but in Mexico occurs in association with igneous dykes, purely a structural relationship.

The colour of an impregnated rock tends to change after impregnation.

Miscellaneous Indications.

Pyrites.—The presence of pyrites in clays indicates reducing conditions of deposition, which are also the conditions necessary for oil formation.

Gypsum.—The association of gypsum is not understood properly. The presence of gypsum implies desiccation and desert conditions, a state not usually associated with oil formation.

Composition of Underground Waters.—The various waters in oil-fields vary greatly in composition. As a general rule the upper waters are not so concentrated as normal sea waters, but the bottom waters are often much more so.

In conclusion the fact to be remembered in dealing with any of these indications is not to study the indication by itself, but to study in conjunction the geology and stratigraphy of the area before any conclusion should be drawn. Although s ructure should be relied upon before the indications, yet if there be an absence of indications, then that structure should be very carefully studied in relation to the stratigraphy and facies developed.

REVIEWS.

"The Microstructure of a Coal Seam." J. Lomax, F.G.S., A.L.S., Fuel Research Board. Tech. Paper No. 11. Pp. xiv.+iii. 50 Illus. H. M. Stationery Office. 4s. 6d. net.

The work deals with the Lanterne Coal Seam of the South Wales Coalfield, which has been selected as a typical example from the numerous coal sections prepared by the Lomax Palæo-Botanical Laboratories. Nearly 100 micrographs (20 diameters magnification) of coal sections are reproduced and described, and the plates are printed by the collotype process, which enables them to be examined in detail with a magnifying glass. The subject-matter is preceded by an introduction by Mr. R. V. Wheeler.

Copies can be obtained from any branch of H.M. Stationery Office or through booksellers.

G. S.

French-English and English-French Technical Dictionary. J. O. Kettridge. Pp. 1160. London: Routledge. £2 10s.

An important work, admirably carried out; we have tested it by words covering several branches of science or industries. Practically, we were able to find equivalents in both languages for their words, taken entirely at random, thus:—

Bisectrix: bissectrice.
Engineer's screwplate: filière.
Rachet wheel and pawl: cuctiquetage.
Plane table survey: levé à la planchette.
Placer mine: exploitation de placers.
Shale oil: huile de schiste.
(Ore dressing) cradle; berceau.
Crank pin; bouton de manivelle.
Creeps (mine working): gouflement.
Critical angle: angle limite.
Cross riveting; rivure en guinconce.
To hole or undercut: haver or sous-caver.
Free fall drilling: forage à chute libre.
Veneering: placage.
Drilling bit: trépan.
Drilling rig: appareil de soude.
Crown block: traverse du haut.
Casing head; tête du tubage.
Tanker: bâteau citerne.
&c., &c.

It is needless to cite more examples; so far as can be ascertained cursorily, it is probably the best book extant of its sort, and can be strongly recommended in these "Great Three" days of literature, English, French and German.

There is an ingenious application of the book, forming a ten-letter code for telegraphic purposes; it is of the simplest nature and likely to be useful.

J. E. M. H.

General Orientative Map of the World's Oil Industry. S. Korytko. Verlag für Fachliteratur G.m.b.H., Vegagasse 4, Vienna XIX.

The map shows the locations of oil-fields, gas-fields, oil-shale deposits, bunkering stations, main pipelines and places where drilling has been undertaken, with inset maps on a large scale of the principal oil-fields. Various diagrams show the world's production of petroleum for 1860 to 1924 by countries and continents, the deepest wells, tonnage of tankers, etc.

The data given on the map is not as accurate as we should like to see it, and the inset and main maps should be more in accord. Oil-bunkering stations

appear to include tank-steamer loading points and should be restricted to ports at which fuel oil can be taken into bunkers. However, the maps serve the purpose of giving some idea of the world's oil industry.

G. S.

A Method of Determining the Dew Points of Fuel-Air Mixtures. Roy J. Kennedy. *U.S. Bureau Standards Scient. Paper* 500 (Feb., 1925).

This paper is an outline of a method developed at the Bureau of Standards for determining the minimum temperatures necessary to keep a mixture of hydrocarbon fuel and air completely vaporised. The theory, apparatus and operation are discussed and the results obtained compared with the Gruse and the Wilson and Barnard methods.

G. S.

Report of Board of Visitors to Bureau of Standards of the Department of Commerce for the Secretary of Commerce. *U.S. Bureau Standards Misc. Publ.* 63 (May, 1925).

The Board of Visitors met at the Bureau of Standards on November 25th and 26th, 1924, and reported upon the work of the Bureau. In dealing with the importance of the work carried out the report states :—"The petroleum industry and the automobile industry jointly called on the Bureau to conduct investigations and to recommend standards of motor fuels. The results were acceptable to both parties, and it is believed that the value of the added gasoline which may be made from the present production of crude oil will amount to about $100,000,000 annually."

G. S.

United States Government Master Specification for Oil Suction and Discharge Hose. *U.S. Bureau Standards Circ.* 209 (April, 1925).

This covers hoses of 4, 6 and 8 ins. internal diameter and gives details of material and physical test requirements.

G. S.

Empire Mining and Metallurgical Congress Proceedings. 5 parts. London, 1925.

The complete report of the proceedings of the Empire Mining and Metallurgical Congress, which was held at the British Empire Exhibition, Wembley, June 3 to 6, 1924, is published in five parts—viz. : I., General ; II., Mining ; III., Petroleum ; IV., Iron and Steel ; and V., Non-Ferrous Metallurgy. Copies are obtainable from the offices of the Congress, Cleveland House, 225, City Road, E.C. 1, at the price of 10s. 6d. per part. Part II., £1 1s., or £2 2s. for the five parts.

The papers read before the Congress, with the discussions thereon, are published in full with many illustrations, and form a complete survey of the mineral resources of the British Empire, together with papers dealing with the special problems and processes arising from their winning. We recommend the work to all interested in the mineral wealth of the Empire, and it will prove to be an invaluable source of information on the subject of mining and metallurgy.

G. S.

The Domestic Grate. Margaret W. Fishenden. *Fuel Research Board, Tech. Paper* 13. H.M. Stationery Office. 1925. 9d. net.

Deals with the design of grates for domestic heating, particularly from the point of view of radiant efficiency, based on work carried out at the Manchester College of Technology with an experimental grate, the constructional details of which were variable.

G. S.